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THE CONSTRUCTION OF THE HEAVENS.

HECTOR MACPHERSON, JUNIOR

FOR POPULAR ASTRONOMY.

Among the problems of astronomy the supreme place is held by that popularly known as the construction of the heavens. Ever since the Copernican system of the world was established, students of the heavens have aspired to a knowledge of the structure of that vaster system, in which the stars and their attendants are mere units. Regarding the great Stellar Universe, the opinions of Copernicus and his immediate successors, Tycho Brahe, Galileo, and Kepler were extremely crude and supported by no observational evidence. More definite and scientific opinions were expressed by Huyghens, who made several interesting calculations on stellar size and distance; but the work of Newton and his successors in gravitational astronomy diverted the attention of astronomers from a question regarding which there was little data on which to build theories. Early in the eighteenth century what was afterwards known as the "disk-theory" of the universe was enunciated by Thomas Wright, a self-taught English astronomer. Similar views were expressed by the philosopher Kant; and some remarkable speculations were made by the German mathematician Lambert. But the scientific study of the subject did not commence until the arrival on the scene of William Herschel, the greatest astronomer of his day and perhaps the greatest observer the world has ever seen.

Herschel saw that before any rational idea of the structure of the heavens could be gained it was necessary to ascertain facts concerning the distribution of the stars. In 1784 he commenced a survey of the heavens, in order to ascertain the number of stars in various parts of the sky. This method, which he named "star-gauging," consisted in counting the number of stars in the telescopic field. Totally he secured 3400 gauges. His studies showed that in the region of the Galaxy, the stars were much more numerous than towards the galactic poles. Sometimes he saw as many as 588 stars in a telescopic field, at other times

only two. Assuming that the stars were on the average of about the same size, and scattered through space with some approach to uniformity, Herschel was able to compute the distance to which his telescope penetrated into space; and, assuming that the universe was limited in extent and that his gauging-telescope was sufficiently powerful to penetrate the Milky Way, he was enabled to sketch the shape and extent of the universe. He concluded that the universe extended in the direction of the Galaxy to 830 times the distance of first magnitude stars. He was enabled to sketch the form of the universe, which he regarded as cloven at one of its extremities, the cleft being represented by the wellknown bifurcation in the Milky Way. The universe was in fact supposed to be a cloven disk and the Milky Way merely a vastly extended portion of it, not a region of actual clustering.

Strange to say, Herschel's original ideas regarding the universe were for many years accepted by astronomical writers. Arago accepted the original theory, unaware that Herschel had in reality abandoned it, and in this he was followed by a host of French and English writers, who did not take the trouble to read each of Herschel's papers, merely quoting that of 1785, and believing it to represent his final views on the subject. Meanwhile, the observations made by Herschel himself proved fatal to the disk theory. Even in 1785 he believed that there were regions in the Milky Way where the stars were more closely clustered than others. "It would not be difficult," he wrote in that year "to point out two or three hundred gathering clusters in our system." These ideas were soon confirmed; and, although in 1799 he still adhered to the disk-theory, in 1802 he wrote—"I am now convinced by a long inspection and continued examination of it that the Milky Way itself consists of stars very differently scattered from those which are immediately about us. This immense starry aggregation is by no means uniform. The stars of which it is composed are very unequally scattered"—a conclusion quite opposed to the disk theory, where the Milky Way was supposed to be merely an extended portion of the universe.

In 1811 Herschel wrote as follows—"I must freely confess that by continuing my sweeps of the heavens, my opinion of the arrangement of the stars and their magnitudes, and some other particulars, have undergone a gradual change; and, indeed, when the novelty of the thing is considered we cannot be surprised that many things formerly taken for granted should on examination prove to be different from what they were generally, but incautiously, supposed to be. For instance, an equal scattering

of the stars may be admitted in certain calculations; but when we examine the Milky Way, or the closely compressed clusters of stars, of which my catalogues have recorded so many instances, this supposed equality of scattering must be given up." This was the virtual abandonment of the disk theory. Six years later, Herschel announced that in six cases he had failed to resolve the Milky Way. This was the abandonment of the second of his assumptions, namely, that his telescope was sufficiently powerful to penetrate to the limits of the universe. Although now an old man, Herschel attacked the question again. In 1817, he devised another method of star-gauging, which Arago and other writers have confused with that of 1785. The two methods, however, were quite distinct. In the first system, one telescope was used on different regions of the heavens; whereas, in the second, various telescopes were used on identical regions. The principle was that the telescopic power necessary to resolve groups of stars indicate the distance at which these groups lie. This, however, also assumed an equal scattering of the stars, and as Proctor remarks—"No question can exist that the principle is unsound, and that Herschel would himself have abandoned it had he tested it early in his observing career.....In applying it, Sir W. Herschel found regions of the heavens very limited in extent, where the brighter stars (clustered like the fainter) were easily resolved with low powers, but where his largest telescopes could not resolve the faintest. These regions, if the principle were true, must be long spike-shaped star-groups, whose length is directed exactly towards the astronomer on Earth—an utterly incredible arrangement."

Herschel's last observation, in 1821, showed that in parts, he could not resolve the Galaxy, even with his forty-foot reflector. In an error of translation into German and French, Struve left the impression that Herschel believed the universe to be infinite in extent—an unfortunate mistake, which hindered the progress of this branch of astronomy for years. So far was Herschel from thinking that the universe was infinite that he still thought some of the star-clusters might be external galaxies, although he had not proved the universe to be limited. Had Herschel lived, he would probably have shown what it was left for the philosopher Herbert Spencer to prove—that all the star-clusters and nebulae which we see are included within the bounds of our finite galaxy. The result of this misapprehension regarding Herschel's ideas was that for half a century the utmost confusion prevailed among astronomers as to what Herschel had actually thought

about the various points under discussion.

After the death of Herschel, little was done to further our knowledge of stellar distribution or the construction of the heavens. In this branch, as elsewhere, Herschel's direct successor was his son, Sir John Herschel, whose star-gauges, both in England and South Africa, were a worthy sequel to those of his father. In his various works on astronomy, John Herschel reproduced the disk-theory, evidently unaware that the elder Herschel had himself abandoned it. The work of the younger Herschel was entirely supplementary to that of his father. To Wilhelm Struve, the great German astronomer belongs the credit of showing that the disk-theory was untenable and that Herschel had himself abandoned it. This he was enabled to do after a perusal of Herschel's papers, presented to him by Sir John Herschel. Having shown this, he undertook a series of investigations which resulted in his own theory of the universe, which appeared in his work, "Etudes d'Astronomie Stellaire" which was published in 1847. Struve's researches were based on the star-catalogues of Bessel, Piazzi and others; and dealing with 52,199 stars, he discussed the number of stars in each zone of Right Ascension. In the words of Mr. Gore, he found "that the numbers increase from hour i to hour vi, where they attain a maximum. They then diminish to a minimum at hour xiii, and rise to another but smaller maximum at hour xviii. As the hours vi and xviii are those crossed by the Milky Way, the result is very significant." Struve considered the phenomenon of the Galaxy to be produced by a collection of irregularly-condensed star-clusters, the stars being condensed in parallel planes. Next, he considered the universe to be infinitely extended in the direction of the Galaxy, and accordingly he put forward the idea that the light from the fainter and more distant stars was extinguished in its passage through space, which he regarded as only imperfectly transparent. But the extinction theory as put forward by Struve was disposed of by Sir John Herschel, who remarked that we were not at liberty to believe that in one portion of the sky, our view was limited by extinction, while at another a view could be had right through the Galaxy; and by the late Professor Grant of Glasgow, who showed that were the theory true, the Galaxy should present a uniform appearance throughout its course. On the whole, Struve's theory was no improvement on Herschel's for, as Encke pointed out, Struve's hypothesis was built on five assumptions, all of which were questionable.

At the time of Struve's investigations, Mädler, at Dorpat, in

Russia, was engaged in an attempt to solve the problem of the construction of the heavens by quite another method, that of stellar proper motion. Mädler, commenced his investigation with a view to discovering the central body of the sidereal system. It was obvious to Mädler, that if such a center existed, the motions near it would be somewhat different from those in the solar system. In the solar system, the planets nearest the Sun move swiftest, owing to the strength of the force of gravitation. In the sidereal system, on the other hand, as Mädler pointed out, the movements at the center would be slowest. As there would be no large preponderating body, the mutual attractions of the different stars would cause the bodies at the boundaries of the universe to move faster than those at the center, the central sun—the object of Mädler's search—being in a state of comparative rest. Accordingly he began to search the heavens for a region of sluggish proper motion. In the constellation Taurus, he noticed that the proper motions of the stars were very slow, and after a most laborious investigation, he announced that the star which fulfilled the conditions of a central body was Alcyone, the brightest of the Pleiades, a group possessed of no proper motion except that due to the Sun's drift in the opposite direction. Mädler's hypothesis was published in 1846 in his work "The Central Sun" and he supplemented it with the sublime thought that the center of the universe was the abode of the Creator. In 1847 Struve rejected Mädler's theory as "much too hazardous"; and this has been the general opinion of astronomers. Mädler's theory is now regarded as quite untenable.

A unique place in the history of this branch of astronomy is held by the researches of R. A. Proctor. Not only did Proctor make fresh discoveries, but it fell to him to clear away the erroneous ideas regarding the construction of the heavens, and to put the study on a new basis. In 1870 Proctor plotted on a single chart all the stars, to the number of 324,198 contained in Argelander's great *Durchmusterung* charts. This work gave the deathblow to the disk theory. In his own words—"In the very regions where the Herschelian gauges showed the stars to be most crowded, my chart of 324,198 stars shows the stars of the higher orders (down to the eleventh magnitude) to be so crowded that by their mere aggregation within the mass they show the Milky Way with all its streams and clusterings. It is utterly impossible that excessively remote stars could seem to be clustered exactly where relatively near stars were richly spread."

Proctor also showed that in all probability the stars composing

the nebulous light of the Galaxy are much smaller than the brighter stars, and not at so great a distance as their faintness would lead us to suppose, a conclusion confirmed by the more recent work of Signor Celoria, now director of the Observatory in Milan. Proctor was not so fortunate in theorizing as in direct investigation. He thought the Magellanic clouds were possibly external galaxies; and further, he put forward the idea that the Milky Way is a spiral, the gaps and "coalsacks" being due to loops in the stream, but neither of these ideas have found favor with astronomers. The chief work accomplished by Proctor was a complete revision of our knowledge of the universe, which he thus describes—"Within one and the same region co-exist stars of many orders of real magnitude, the greatest being thousands of times larger than the least. All the nebulæ hitherto discovered, whether gaseous or stellar, irregular, planetary, ring-formed or elliptic exist within the limits of the sidereal system. They all form part and parcel of that wonderful system, whose nearer and brighter parts constitute the glories of our nocturnal heavens."

Proctor's discovery of the excess of bright stars on the Galaxy was confirmed by the researches of the late J. C. Houzeau, director of the Brussels Observatory, and some time later by Mr. J. E. Gore, the famous Irish astronomer. Mr. Gore carefully examined the positions of all the bright stars in both hemispheres, and following this he made an enumeration of the stars in the atlas of Heis and the charts of Harding. The outcome of Mr. Gore's investigation was to show that stars of each individual magnitude, taken separately, tend to aggregate on the Galaxy, the clustering being noticed even in the case of first magnitude stars. Mr. Gore further pointed out the close connection between the lucid stars and the galactic light. A similar investigation was undertaken in 1889 by the great Italian astronomer Professor Schiaparelli, formerly director of the Milan Observatory. Basing his work on the catalogue of Gould and the photometric measures of Professor Pickering, Professor Schiaparelli constructed a series of planispheres which demonstrated the crowding of the lucid stars towards the galactic plane. These investigations were still further continued by Professor Simon Newcomb, who demonstrated that "the darker regions of the Galaxy are only slightly richer in stars visible to the naked eye than other parts of the heavens, while the bright areas are between 60 and 100 per cent richer than the dark areas."

Perhaps the most elaborate investigation yet made on the construction of the heavens is that of the Dutch astronomer, Pro-

fessor Kapteyn, who commenced his researches in this branch of astronomy in 1891. In that year he demonstrated that stars are bluer and more easily photographed in the Galaxy than elsewhere, a discovery confirmed by Sir David Gill and Professor Pickering. In 1893 Professor Kapteyn announced the conclusions drawn from his investigations, derived from a novel method of studying the distances of the stars from their proper motions. In order to reach a definite idea of the distances of the stars he made use of the component of the proper motion measured at right angles to a great circle of the sphere which passes through a given star and the apex of the solar motion. He found that stars of the first spectral type have smaller proper motions than those of the second, indicating that stars of the second type are on the average nearer to the solar system than those of the first, the near vicinity of the Sun containing almost exclusively second-type stars. Professor Kapteyn concluded that this group of second-type stars formed one system, which he termed the solar cluster, believed by him to be roughly spherical in shape. In 1902 he abandoned the idea of a solar cluster, retaining however his opinions as to the relative distance of the different types. As Dr. Kapteyn remarked in a letter to the writer, that the second-type stars are, on the average, nearer to the solar system than the first, is an incontrovertible fact.

The structure and extent of the universe were ably discussed by Professor Simon Newcomb in his work "The Stars" which appeared in 1901. He considers, that the universe is limited in extent, in accordance with the original views of Herschel, and in opposition to the opinions of Struve. He has brought clearly before his readers a calculation—originally mentioned by Olbers—based on the known fact that there are three times as many stars of any given magnitude as of that immediately brighter, the increase of number compensating for the decrease of brilliance. Were the universe infinitely extended the whole heavens would shine with the brilliance of the Sun. Professor Newcomb, therefore, concludes that "that collection of stars which we call the universe is limited in extent". Positive evidence that this is the case was obtained by Professor Celoria, in the course of a series of star-gauges at the north galactic pole. Using a small refractor, showing stars barely to the eleventh magnitude he was enabled to see exactly the same number of stars as Herschel's large reflector, indicating that increase of optical power will not increase the number of stars visible in that direction. Professor Celoria's observation can only be explained on the assumption that the

universe is limited in extent. Otherwise, Herschel's telescope would have shown more stars than Celoria's, even granting an extinction of light, which theory—at least as advanced by Struve,—has been shown by Professor Newcomb, Dr. Seeliger, Professor Schiaparelli and others to be absolutely untenable. That the visible universe is limited in extent seems to be about all that we know for certain concerning the structure of the heavens, and even this has been questioned by Mr. Maunder, Professor Turner and other English astronomers, in their reply to the famous theory of Dr. Russel Wallace; but here the English astronomers forgot that on one point, that of the extent of the universe, Dr. Wallace and the majority of astronomers are in complete agreement.

A series of investigations on stellar distribution commenced in 1884 by Professor Seeliger, director of the Munich Observatory have led that distinguished astronomer to some remarkable conclusions. Professor Seeliger believes the universe to be flattened at the galactic poles the Galaxy itself representing the zone of stellar condensation. He computes the distance of the solar system from the inner border of the zone to be about 500 times the distance of Sirius, while the external border of the universe is at 1100 times that distance. The universe is finite in extent, its limits being about 9000 light years from the solar system. In Professor Seeliger's opinion, the extinction of light may come into play beyond our universe, and prevent us seeing other possible collections of stars—external universes.

The question of external universes is purely a hypothetical one; we have never seen these universes, and probably never will. Still there is much to be said in favor of the idea. The question was approached from a scientific standpoint by Mr. Gore, in his masterly work "The Visible Universe," which should be perused by every student of the sublime problem. Mr. Gore regards the solar system as a system of the first order, and the Galaxy and its hypothetical fellow-universes as of the second, the Galaxy bearing the same relation to its fellow-universes that the solar system bears to the systems of Sirius or Alpha Centauri, or—to go lower in the scale—the Earth-Moon system to the satellites of Jupiter. Assuming that the distance between the Galaxy and the nearest external universe is proportional to that separating the Sun from Alpha Centauri, he reaches the amazing conclusion that the distance of the nearest Galaxy is no less than 520,149,600,000,000,000 miles, a distance which light,—which darts from the Earth to the Moon in a second and a half,

and across the solar system in eight hours—with an inconceivable velocity of 186,000 miles a second, would take nearly ninety millions of years to traverse. Truly, as M. Flammarion says, our Milky Way is but a point in the Infinite. These calculations absolutely overwhelm the mind, and here science must give way to religion. Mr. Gore sums up his masterly investigation with the following noble words—"Although we must consider the number of *visible* stars as strictly finite, the number of stars and systems really existing but invisible to us may be practically infinite. Could we speed our flight through space on angel wings beyond the confines of our limited universe to a distance so great that the interval which separates us from the remotest fixed star might be considered as merely a step on our celestial journey, what further creations might not then be revealed to our wondering vision! Systems of a higher order might there be unfolded to our view, compared with which the whole of our visible heavens might appear like a grain of sand on the ocean shore, systems perhaps stretching out to infinity before us, and reaching at last the glorious "mansions" of the Almighty, the Throne of the Eternal."

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ASTRONOMICAL OBSERVATIONS OF THE FLOWER OBSERVATORY OF THE UNIVERSITY OF PENNSYLVANIA, PUBLISHED BY THE UNIVERSITY, PHILA., 1905.

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FOR POPULAR ASTRONOMY.

The work which we review is volume II, parts II, and III, consisting of observations with the zenith telescope, for variation of latitude and constant of aberration, by Professor C. L. Doolittle, Director of the Flower Observatory, and of measures of 1066 Double and Multiple stars, made with the 18 inch Refractor by Professor Eric Doolittle. It is a notable contribution to current astronomical literature, and sure to prove of lasting value, because the methods and principles underlying the work have been well thought out, and the observations themselves taken with care, and adequately discussed. In fact the form in which this work is presented to the reader is classic, and leaves little to be desired either in the way of the subject matter chosen or in its manner of treatment.

The Flower Observatory was designed for carrying on certain special lines of work, and the results already attained furnish a good illustration of what may be done in Astronomy today with very modest equipment but competent direction and energetic use of the available appliances. It is generally recognized by experienced astronomers that there is not a branch of our science today in which important discoveries and improvements may not be made; for even Astronomy, the oldest of the sciences, is still in its infancy in many lines, and none of the results heretofore obtained are considered final. Some of the lines of thought engaging the attention of astronomers are directed to exploring new fields, while others are applied to the improvement of fields already partially explored. One of these lines of activity is as important as the other, because the reworking of partially known fields brings to light new and more accurate methods, as well as unexpected phenomena which often have a bearing on all branches of Astronomy. Thus the attainment of higher precision, with the resulting improvement in the standard of science, more than compensates for lack of novelty in the problem under consideration. Problems which are entirely new usually are enveloped in great uncertainty for decades, and sometimes for generations; so that all have to be worked and reworked, and thus the two lines of science are ultimately merged into one fairly homogeneous whole, which is always growing. The Flower Observatory is devoted to two standard lines of work, involving very precise measurements by experienced observers; it is one of the new observatories of our country conducted on a par with the best institutions of similar character abroad; and although but recently established already takes high rank in the world of science.

Part II, devoted to Professor C. L. Doolittle's work, consists of 106 pages of closely printed matter, most of it in the form of tables which have been calculated and arranged with much care, and evidently involved great labor.

The observations extend from October 1, 1901 to December 28, 1903, and the discussion includes a rediscussion of the series of observations taken in 1896-1898. The stars used are distributed in four groups, one in each six hours of right ascension, so as to get the constant of observation as well as the variation of latitude, which are shown by theory to be somewhat interconnected. In 1901, 1819 observations were made; in 1902, 1786; in 1903, 1971; all the measures, except 300, being taken by Professor Doolittle himself, who also carried out nearly all

the reductions. Two groups of stars, separated by an interval of six hours, were taken on each night whenever practicable, so that the labors of the observer were scattered throughout the night.

After full discussion of the results of this series Professor Doolittle gets for the constant of aberration

20.″513, 1901 Oct. 1, to 1902, Dec. 1.
30.″524, 1902 Dec. 1, to 1903, Dec. 7.

In the rediscussion of the series 1896-1898, slight changes are made in the values formerly published. The above values of the aberration constant are near that found from all his work, involving more than 15000 observations, all carefully discussed. Doolittle's work on this important constant is sure to supplant that of Nyrèn, heretofore very generally used by astronomers for nearly a quarter of a century.

At the end of the paper under review a discussion of the observed variation of latitude is given, with a plate illustrating the concluded mean path of the Zenith among the stars and the deviations from regularity resulting from the observations. The cause of these anomalies, which occasionally are as large as 0.″8, some days on one side of the mean, then again on the other, is not yet fully understood. These quantities, however, are on the very limit of measurement, even with the finest instruments, and it is not remarkable that these small anomalies should appear. Assuming that they are real, some astronomers have supposed them to be due to great movements in the atmosphere, involved in the formation of storms in different parts of the Earth, producing thereby a very small oscillation in the instantaneous position of the pole.

Part III deals with the measures of 1066 double and multiple stars made with the 18-inch Brashear refractor by Professor Eric Doolittle in years 1900-1904. This work is a continuation of that contained in Part III of vol. I., and is a notable contribution to the literature of double stars. The stars selected for measurement are grouped as follows: 733 from the catalogues of Burnham; 109 from Otto Struve, 102 from W. Struve; 55 from W. Herschel; and a few other miscellaneous pairs. Professor Eric Doolittle has also measured nearly all the stars discovered by Hough, but the results are reserved for a later publication, which will prove of lasting value to science and be awaited with much interest. The measures contained in the present work fill 180 quarto pages of printed matter closely set in double columns. The measures on each night are given, with the mean of the work

usually on at least three nights each year. Many of the stars are close and difficult, and quite a number exhibit orbital motion. In each case the record of the measures is accompanied by the mean, and followed by brief remarks on the motion, where any is sensible. Comparisons are also made with the published orbits of revolving binaries, so that the work gives the latest data on the particular stars measured, in the briefest and simplest form. It is needless to say that such a work is of the highest value.

In recent years nothing has been more conspicuous than the progress of double star astronomy, and it is gratifying to note that America has taken the lead in this promising and important branch of science. Thirty years ago very few double stars were observed in this country, and scarcely any had been discovered by Americans, while those long ago discovered in Europe by the Herschels and Struves were measured by but few observers. Since that time our country has witnessed the epoch-making work of Burnham, and a long series of measures by Hall. In more recent years Hough, See, Aitken, Hussey, Eric Doolittle, and others have made notable contributions.

The discovery of more than 2000 of these objects by Hussey and Aitken at the Lick Observatory within the last ten years is a fair indication of the growing importance of this branch of science. Added to this we have now about 150 spectroscopic binaries, most of them with periods of but a few days, and having direct connection with visual binaries through δ Equulei, which Hussey showed to revolve in about 5.5 years. Spectroscopists such as Campbell and Frost, to whom we owe most of the spectroscopic binaries, think that from one fifth to one third of all the stars in the sky are multiple, so that the number of sidereal systems in nearly infinite. But although we may infer a vast number of such systems to exist, we have observed only a few: namely some 6000 stars seen to be double in our telescopes, and about 150 inferred to be double from periodic motions of the lines of their spectra.

The spectroscopic binaries give us valuable data respecting systems too close to be seen in any telescope; but we must always rely for our knowledge of sidereal systems mainly on visual binaries, which are made the basis of interpreting the spectroscopic binaries. Without a good knowledge of visual binaries spectroscopic binaries could never have been discovered, and the observed changes in the spectra would have simply bewildered and perplexed the spectroscopist.

In the progress of double star astronomy it is the systematic

work of observers like Burnham, Hussey, Aitken and Doolittle that counts. These have all made valuable contributions to our knowlege in recent years; but none of these contributions have been of higher class or more carefully done than the systematic measures made by Professor Eric Doolittle at the Flower Observatory. Accordingly one may heartily congratulate the University of Pennsylvania on the large amount and high quality of the researches already produced by the Flower Observatory under the direction of Professor C. L. Doolittle, and wish him and his son many years of uninterrupted activity in the important work which has already made Philadelphia such an important astronomical center.

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A CONVENIENT METHOD FOR COMPUTING, FROM ELEMENTS, THE DAILY MOTION IN GEOCENTRIC RIGHT ASCENSION AND DECLINATION.

RUSSELL TRACY CRAWFORD.

For Popular Astronomy.

In Popular Astronomy No. 135 (May 1906) Professor Herbert L. Rice of the Naval Observatory gives a method of computing the daily motion in geocentric right ascension for an asteroid whose elements are given. A somewhat more convenient method follows directly from the developments which arise in Leuschner's "Short Method" for determining orbits, and, as will be seen from the example, involves only about two thirds of the computing necessary in Rice's method.

For the sake of completeness the portions of the method common to the two will be given here also.

Let the elements M_0, ϕ, a, μ, Ω, ω, and i be given.

The last three referred to the mean equinox and equator of Jan. 0 of the year T_0. The mean equinox and equator of the year T_0 will be taken as the reference point and plane for all the coördinates in the work. This means that the solar coördinates taken from the Jahrbuch or American Ephemeris must be reduced to this equinox and plane. Professor Rice gives very convenient expressions for these, which are embodied in the collection of formulæ here given.

We have

$$\left.\begin{aligned}\Delta \cos\delta \cos\alpha &= \xi = x + X_0\\ \Delta \cos\delta \sin\alpha &= \eta = y + Y_0\end{aligned}\right\} \quad (1)$$

$$\tan\alpha = \frac{\eta}{\xi} \quad (2)$$

Differentiating (2) with respect to the time we have

$$\alpha' = \frac{\xi\eta' - \eta\xi'}{\xi^2 \sec^2\alpha} = \frac{\xi\eta' - \eta\xi'}{\xi^2 + \eta^2} \quad (3)$$

In this form α' will be expressed in radians per mean solar day. To reduce it to seconds of time per mean solar day divide by 15 sin 1″, giving

$$\alpha' = \frac{1}{15 \sin 1''} \cdot \frac{\xi\eta' - \eta\xi'}{\xi^2 + \eta^2} \quad (4)$$

If we have ξ, η, ξ', and η' (the velocities being per mean solar day), (4) gives the desired result in α. The divergence from Rice's method begins at this point. To find ξ and η compute the constants for the equator for T_0 from the elements, i.e. only those that are necessary, viz. sin a, sin b, A', and B'. To get ξ' and η' differentiate (1) with respect to the time.

$$\left.\begin{aligned}\xi' &= x' + X'\\ \eta' &= y' + Y'\end{aligned}\right\} \quad (5)$$

X' and Y' can be found from the data of the Jahrbuch or American Ephemeris by mechanical differentiation: x' and y' are found by differentiating the constants for the equator with respect to the time. This is a process which has been used here for the past year in orbit work according to Leuschner's "Short Method".

We have

$$\left.\begin{aligned}x &= r \sin a \sin (A' + v)\\ y &= r \sin b \sin (B' + v)\end{aligned}\right\} \quad (6)$$

Differentiating the first of (6) with respect to the time gives

$$x' = r' \sin a \sin (A' + v) + r \sin a \cos (A' + v) \frac{dv}{dt} \quad (7)$$

From the well known relations

$$r^2 \frac{dv}{dt} = k\sqrt{p}$$

and

$$r = \frac{p}{1 + e\cos v}$$

we have

$$r\frac{dv}{dt} = \frac{k(1 + e\cos v)}{\sqrt{p}} \quad (8)$$

and

$$r' = \frac{p\, e \sin v}{(1 + e\cos v)^2} \quad \frac{dv}{dt} = \frac{k\, e \sin v}{\sqrt{p}} \quad (9)$$

Substituting (8) and (9) into (7) we have

$$x' = \frac{k(1+e\cos v)}{\sqrt{p}} \sin a \cos(A'+v) + \frac{k\,e \sin v}{\sqrt{p}} \sin a \sin(A'+v)$$

$$\left.\begin{aligned} x' &= \frac{k}{\sqrt{p}} \sin a\,[\cos(A'+v) + e\cos A'] \\ \text{Similarly}\quad y' &= \frac{k}{\sqrt{p}} \sin b\,[\cos(B'+v) + e\cos B'] \end{aligned}\right\} \quad (10)$$

COLLECTION OF FORMULÆ

t = the date for which α' is required.

Ω, ω, i = elements referred to mean equinox and equator of Jan. 0 of the year T_0.

T = the year of the date t.

X, Y = Sun's equatorial rectangular coördinates for the time t, referred to the mean equinox and equator of Jan. 0 of the year T.

X_0, Y_0 = the corresponding coördinates referred to the mean equinox and equator of Jan. 0 of the year T_0.

$X_0 = X + 2657\ Y(T-T_0)$ } where the numerical coefficients are in
$Y_0 = Y - 2236\ X(T-T_0)$ } units of the seventh decimal place.

$T-T_0$ must be expressed in years.

X', Y' by mechanical differentiation.

$\sin a \sin A = \cos\Omega$ $\qquad A' = A + \omega$

$\sin a \cos A = -\sin\Omega\cos i$ $\qquad B' = B + \omega$

$\sin b \sin B = \sin\Omega\cos\epsilon$

$\sin b \cos B = \cos\Omega\cos i\cos\epsilon - \sin i\sin\epsilon$

r and v by any of the usual methods.

$x = r \sin a \sin(A'+v)$

$y = r \sin b \sin(B'+v)$

$\xi = x + X_0$

$\eta = y + Y_0$

$$x' = \frac{k}{\sqrt{p}} \sin a\,[\cos(A'+v) + e\cos A']$$

$\log k = 8.23558$

$$y' = \frac{k}{\sqrt{p}} \sin b\,[\cos(B'+v) + e\cos B']$$

$\xi' = x' + X'$

$\eta' = y' + Y'$

$$\alpha' = \frac{1}{15 \sin 1''} \cdot \frac{\xi\eta' - \eta\xi'}{\xi^2 + \eta^2}$$

$\log 15 \sin 1'' = 5.86166$

As an application of these formulæ, the computation is here given for the same case that Professor Rice used. That part of the computation giving X_0, Y_0, and X', Y', being the same in the two methods is not repeated here. I have preferred to derive r and v by the simple method of Tietjen ("Tafel zur Berechnung der wahren Anomolie"). The computation is here given to five places although four would have been sufficient.

DETERMINATION OF THE DAILY MOTION IN α of (198) AMPELLA

FOR $t = 1903$, DEC. 24.0 BERLIN M. T.

ELEMENTS (from Jahrbuch 1905).

Epoch =	1903, Nov. 25.0 B. M. T.	
M_0 =	51° 39′ 40″	
ω =	87 15 50	}
Ω =	268 28 17	} 1900.0
i =	9 18 45	}
ϕ =	13 6 49	
log a =	0.39073	
μ =	920.″2	

Constants for Equator 1900.0

sin Ω	9.99984_n	$t - t_0$	+ 29.0
cos i	9.99424	$(t - t_0)\ \mu$	7° 24′ 46″
sin a cos A	9.99408	M	59 4 26
sin a sin A	8.42612_n		
$tg\ A$	8.43204_n	dM'	4.′43
A	− 1° 32′ 56″	$dM°$	0.°074
A'	85 42 54	$d\phi'$	+ 6′.82
sin a	9.99424	$dv/d\phi$	2.0654
		$[D\ dv/d\phi]\ dM'$	0
		$\Delta\phi\ \delta\phi/20$	+ 5
		$\Sigma\ d\phi'$	+ 14′.09
cos ε	9.96256	$d(v - M)\ /\ dM$	0.1326
log I	8.38292_n	$½\ D_m\ dM°$	− 3
		$\Sigma\ dM'$	+ 0.59
sin i	9.20903	$v - M$	24° 58.73
sin ε	9.59986	$v_1 - M$	25 13.41
log II	8.80889	v	84° 17′ 51″
sub.	0.13830		
sin b cos B	8.94719_n	$A' + v$	170 0 45
sin b sin B	9.96240_n	$B' + v$	76 2 46
$tg\ B$	1.01521		
B	264° 29′ 5″	cos v	8.99723
B'	351 44 55	e cos v	8.35303
sin b	9.96441	log (1 + e cos v)	0.00968
		log r	0.35810
log e^2	8.71160		
log $(1 - e^2)$	9.97705		
log p	0.36778		

P =	A	B
sin $(P' + v)$	9.23913	9.98699
log x; log y	9.59147	0.30950
log X; log Y	8.38876	9.95520_n
add	0.02641	0.10071
log ξ; log η	9.61788	0.05591
cos $(P' + v)$	9.99336_n	9.38227
e cos P'	8.22922	9.35128
add	9.99246	0.28581
Sum	9.98582_n	9.66808
log x': log y'	8.03175_n	7.68418
log X'; log Y'	8.24264	6.65321
add	9.79597	0.03867
log ξ'; log η'	7.82772	7.72285
log $\xi\ \eta'$	7.34073	
log $\eta\ \xi'$	7.88363	
sub.	9.85340	
log numer.	7.73703_n	

P =	A	B
log ξ^2	9.23576	
log η^2	0.11182	
add	0.05424	
log denom.	0.16606	
log a' (rad)	7.57097_n	
log a'	1.70931_n	
a'	$-51^s.205$	

It may be noted here that Professor Rice's formula (p. 292)

$$da = [8.8373]\left(\frac{Q}{q} - \frac{P}{p}\right) \sin 2\,a$$

is equivalent to

$$da = \frac{pQ - qP}{p^2 + q^2}$$

which is the same as my formula (3). This form simplifies his computation by eliminating the constant and the angle $2a$.

It will be noticed that in cases where the constants for the equator are known the computation is much shortened. Furthermore, in computing an ephemeris, say for a comet, very little additional work is necessary to get the daily motion in α, δ and ρ or log ρ. Such data will be very useful in simplifying the interpolation in deriving positions for times other than those for the ephemeris dates.

For this purpose the additional necessary expressions are here derived.

Differentiating $\rho^2 = \xi^2 + \eta^2 + \zeta^2$ with respect to the time we have

$$\rho\rho' = \xi\xi' + \eta\eta' + \zeta\zeta' \qquad (11)$$

Hence

$$\rho' = \frac{1}{\rho}\,(\xi\xi' + \eta\eta' + \zeta\zeta'] \qquad (12)$$

or

$$(\log \rho)' = \frac{\text{Mod.}}{\rho^2}\,(\xi\xi' + \eta\eta' + \zeta\zeta') \qquad (13)$$

Further $\rho \sin \delta = \zeta$

whence $\rho' \sin \delta + \rho \cos \delta\delta' = \zeta'$

and

$$\delta' = \frac{\zeta' - \rho' \sin \delta}{\rho \cos \delta \sin 1''} \qquad (14)$$

(13) gives $(\log \rho)'$ and (14) gives δ' as soon as ζ' is known.

Proceeding similarly to the development of (10) we have $\zeta' = z' + Z'$

where

$$z' = \frac{k}{\sqrt{p}} \sin c\,[\cos (C' + v) + e \cos C'] \qquad (15)$$

In case the orbit is parabolic ($e = 1$, and $p = 2q$) (10) and (15) are simplified and can be written

$$\left.\begin{aligned} x' &= k\sqrt{\frac{2}{q}}\ \cos \tfrac{1}{2}\ v \sin a \cos (A' + \tfrac{1}{2}\ v) \\ y' &= k\sqrt{\frac{2}{q}}\ \cos \tfrac{1}{2}\ v \sin b \cos (B' + \tfrac{1}{2}\ v) \\ z' &= k\sqrt{\frac{2}{q}}\ \cos \tfrac{1}{2}\ v \sin c \cos (C' + \tfrac{1}{2}\ v). \end{aligned}\right\} \qquad (16)$$

As Professor Rice points out, these daily motions, thus computed, are for the α and δ referred to the mean equinox and equator. To them, therefore, should be added the daily rate of variation due to changing from the mean to the true equinox and equator.

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SOME PROBLEMS ON THE ORTHOGRAPHIC PROJECTION OF THE SPHERE.

I. TRANSFORMATION OF COÖRDINATES.

Wm. F. RIGGE S. J.

For Popular Astronomy.

When a sphere is orthographically projected upon a plane, the location of a point on its surface and of its projection upon the plane is determined by certain systems of coördinates, the interrelation of which it is the object of this article to examine. In order the better to fix our ideas, let us take the terrestrial sphere as seen from a star. The plane of projection will then be the background of the sky. As projections upon parallel planes are identical, let us for the sake of convenience pass this plane through the center of the sphere and call it the fundamental plane. Let the elevation of the north end of the Earth's axis above the plane of projection be called δ, an angle evidently equal to the star's declination.

In Fig. I the plane of the paper is the fundamental plane, and the large circle is the intersection with it of the terrestrial sphere; P is the projected north pole, aud X^1EX the equator. The axis of Y lies on the projected axis of the Earth, and the axis of X is

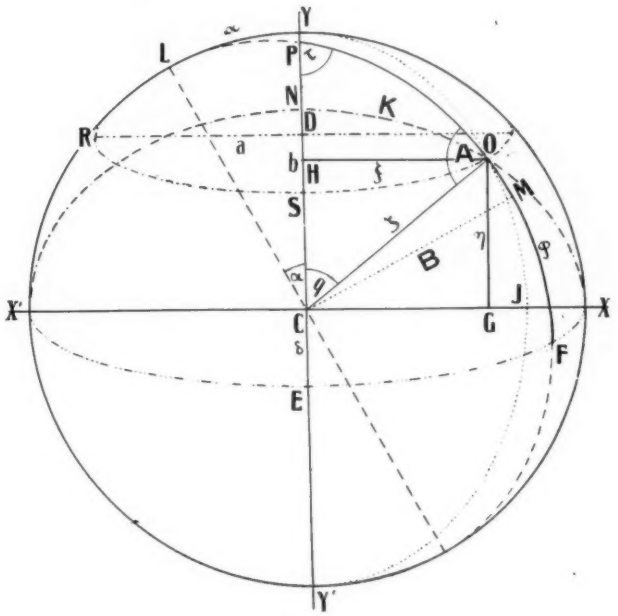

FIGURE 1.

drawn at right angles to it at the center C. The equator is projected into an ellipse, whose semi-major axis CX is equal to the radius of the sphere, or unity, and whose semi-minor axis CE is equal to sin δ. The parallels of latitude are projected into ellipses of the same eccentricity, the semi-major axis of anyone being $RD = a = \cos \phi$, and its semi-minor axis $DS = b = \cos \phi \sin \delta$, $OF = \phi$ being the latitude of the parallel. The ordinate of the center of the ellipse $CD = d = \sin \phi \cos \delta$.

The meridians, being great circles of the sphere, are projected into ellipses whose semi-major axes are equal to unity. The semi-minor axis of any one is $CM = B = \sin \tau \cos \delta$, in which τ is the angle OPC between the given meridian and the central meridian which is projected upon the axis of Y. The same angle τ is also the hour angle of a point, such as O, on a given meridian, as seen from the star, or the hour angle of the star as seen from the place O. The major axes of the parallel ellipses are parallel to the axis of X, but those of the meridian ellipses make an angle $LCY = \alpha$ with the axis of Y such that $\tan \alpha = \tan \tau \sin \delta$.

The position of a point, such as O, on the surface of the sphere is

determined by two systems of spherical coördinates. The first system consists of latitude ϕ ($= OF$) and hour angle τ ($= OPC$). The latter angle $\tau = \mu - \lambda$, in which μ is the longitude of the central meridian and λ that of the point. The second system consists of the star's local zenith distance ζ, or the arc OC, and its local azimuth A, or the angle POC.

The projection of the point O on the fundamental plane is determined by two systems of plane coördinates. The first system is rectangular and consists of ξ ($= OH$) and η ($= OG$). (This is the notation of the American Ephemeris, which reserves x and y for the center of the umbra or penumbra). The second system is polar and consists of $\sin \zeta$, or the straight line OC, and the angle q, or OCY, which is the parallactic angle at the star as seen from the place O.

There are therefore four systems of coördinates, two spherical and two plane, which determine the position of the point O on the sphere and on the plane of projection. The elevation of the Earth's axis above the plane of projection, the arc PY, or its equivalent CE, the star's declination, δ, being given, the position of the point O both on the sphere and on the plane is determined by any two coördinates in the four systems enumerated, whether they be homogeneous or mixed, that is, whether they belong to the same system or to different systems. These same two given coördinates will enable us to compute the remaining ones in the other systems.

As the four systems mentioned consist each of two coördinates, there are eight coördinates in all. As one of these appears as an arc in one system and as its sine in another, ζ and $\sin \zeta$, there are in reality only seven. These seven, taken two at a time, form twenty-one combinations.

In the equations which are to follow the two given coördinates are always used to determine ϕ and τ. As ϕ and τ themselves constitute one of the twenty-one possible combinations, the number of cases is reduced to twenty. If the remaining coördinates are wanted they may be found from ϕ and τ by the equations

$$\xi = \cos \phi \sin \tau$$
$$\eta = \sin \phi \cos \delta - \cos \phi \sin \delta \cos \tau$$

$$\tan q = \frac{\xi}{\eta}$$

$$\sin \zeta = \frac{\xi}{\sin q} = \frac{\eta}{\cos q}$$

$$\sin A = \frac{\cos \delta \sin \tau}{\sin \zeta} = \frac{\cos \delta \sin q}{\cos \phi}.$$

In the equations given below M is the arc MF on Fig. I., N the arc NC, J the arc OJ, K the arc ON and R and g are auxiliary quantities for which no geometrical realities could be found.

Given

1. ϕ, ζ $\quad \sin \tfrac{1}{2}\tau = \sqrt{\dfrac{\sin \tfrac{1}{2}[\zeta + (\phi - \delta)] \sin \tfrac{1}{2}[\zeta - (\phi - \delta)]}{\cos \phi \cos \delta}}$

$$\cos \tau = \frac{\cos \zeta - \sin \phi \sin \delta}{\cos \phi \cos \delta}$$

2. ϕ, A $\quad \sin q = \sin A \cos \phi \sec \delta$

$$\tan \tfrac{1}{2}\tau = \frac{\sin \tfrac{1}{2}(\phi - \delta)}{\cos \tfrac{1}{2}(\phi + \delta) \tan \tfrac{1}{2}(A - q)}$$

3. ϕ, ξ $\quad \sin \tau = \xi \sec \phi$

4. ϕ, η $\quad \cos \tau = \dfrac{\sin \phi \cos \delta - \eta}{\cos \phi \sin \delta}$

5. ϕ, q $\quad \sin A = \cos \delta \sin q \sec \phi$

$\tan \tfrac{1}{2}\tau$ as in No. 2

6. τ, ζ $\quad \tan M = \tan \delta \sec \tau$

$\sin A = \cos \delta \sin \tau \csc \zeta$

$\tan (\phi - M) = \tan \zeta \cos A$

$\phi = (\phi - M) + M$

7. τ, A $\quad \tan M = \tan \delta \csc \tau$

$\sin (\phi - M) = \tan \tau \cos M \cot A$

$\phi = (\phi - M) + M$

8. τ, ξ $\quad \cos \phi = \xi \csc \tau$

9. τ, η $\quad \sin J = \eta$

$\sin f = \sin \delta \sin \tau \sec J$

$$\tan \tfrac{1}{2}(90 - \phi) = \frac{\cos \tfrac{1}{2}(\tau - f)}{\cos \tfrac{1}{2}(\tau + f)} \tan \tfrac{1}{2}(90 - J - \delta)$$

10. τ, q $\quad \tan \tfrac{1}{2}[\zeta + (90 - \phi)] = \dfrac{\cos \tfrac{1}{2}(\tau - q)}{\cos \tfrac{1}{2}(\tau + q)} \tan \tfrac{1}{2}(90 - \delta)$

$$\tan \tfrac{1}{2}[\zeta - (90 - \phi)] = \frac{\sin \tfrac{1}{2}(\tau - q)}{\sin \tfrac{1}{2}(\tau + q)} \tan \tfrac{1}{2}(90 - \delta)$$

$$\phi = 90 - \left[\tfrac{1}{2}[\zeta + (90 - \phi)] - \tfrac{1}{2}[\zeta - (90 - \phi)]\right]$$

11. ζ, A $\quad \sin \tau = \sin A \sin \zeta \sec \delta$

$\tan M = \tan \delta \sec \tau$

$\sin (\phi - M) = \tan \tau \cos M \cot A$

$\phi = (\phi - M) + M$

12. ζ, ξ $\quad \sin K = \xi \qquad \sin q = \xi \csc \zeta$

$\tan N = \tan \zeta \cos q$

$\sin \phi = \cos K \sin (N + \delta)$

$\tan \tau = \tan K \sec (N + \delta)$

13. ζ, η $\quad \cos q = \eta \csc \zeta$

$\tan N = \eta \sec \zeta$

$\sin K = \sin \zeta \sin q$

$\sin \phi$ and $\tan \tau$ as in No. 12.

14. ζ, q $\quad \tan N = \tan \zeta \cos q$

$\sin K = \sin \zeta \sin q$

$\sin \phi$ and $\tan \tau$ as in No. 12

15. A, ξ $\quad \sin K = \xi \qquad \cot R = \xi \cot A$

$$\cos g = \frac{2 \sin (R + \delta - 90)}{\sin K \cos^2 K} - \sin \delta$$

$$N = \tfrac{1}{2}(g - \delta + 90)$$

$\sin \phi$ and $\tan \tau$ as in No. 12.

16. A, η $\quad$ No practical solution could be found for this case.

17. A, q	$\cos\phi = \cos\delta \sin q \csc A$ $\tan \frac{1}{2}\tau$ as in No. 2.
18. ξ, η	$\sin K = \xi$ $\sin N = \eta \sec K$ $\sin\phi$ and $\tan\tau$ as in No. 12.
19. ξ, q	$\sin K = \xi$ $\sin\zeta = \xi \csc q$ $\tan N = \tan\zeta \cos q$ $\sin\phi$ and $\tan\tau$ as in No. 12
20. η, q	$\sin\zeta = \eta \sec q$ $\tan N = \eta \sec\zeta$ $\sin K = \sin\zeta \sin q$ $\sin\phi$ and $\tan\tau$ as in No. 12.

The practical application of these formulæ is almost unlimited. If the plane coördinates ξ and η are replaced by their equivalent spherical arcs K and J of which they are the sines, these twenty formulæ give the key to the solution of all possible problems in spherical trigonometry and astronomy. When the coördinates given are mixed, that is, when one is spherical and the other plane, the formulæ may be used to construct eclipse maps which will show all the places at which the position angles of the points of contact are the same or equal to any magnitude, or at which the Sun's vertex is the same, or at which the eclipse begins or ends at a certain local hour angle or altitude or azimuth, or attains any magnitude. The ingenuity of the student will easily find numberless other practical applications.

II. GEOMETRICAL CONSTRUCTIONS.

Problems of geometrical constructions are divisible into two classes. In the first, lines, circles or figures of any kind on the fundamental plane are to be transferred to the surface of the sphere. In the second the reverse is the case, lines, and especially great and small circles on the surface of the sphere are to be projected upon the plane.

1. From the Plane to the Sphere.

1. In Fig. 2 let it be required to transfer the straight line ADB on the fundamental plane to the surface of the sphere. As we are dealing with orthographic projection, this line may be considered as the projection upon the fundamental plane of the intersection of the sphere by a second plane perpendicular to the fundamental plane. As the intersection of a sphere and a plane is a circle, the straight line ADB on the fundamental plane will become a circle or a part of one when transferred to the sphere. In order to locate this circle properly, let us turn to Fig. 1 and study the straight line RD. This is the semi-major axis of a parallel ellipse. Its length is equal to $\cos\phi$, and its distance CD from the center is $\sin\phi\cos\delta$. Let us now in imagination turn the sphere about the axis of X through the angle δ: then the

point E will fall on C, P on Y, and δ will be zero. The line $RD = \cos\phi$, being independent of δ and remaining parallel to the fundamental plane, is not changed in length, but its distance from the center, CD, which was $\sin\phi\cos\delta$, has now become $\sin\phi$. Turning now to Fig. 2 and making the application, we see that

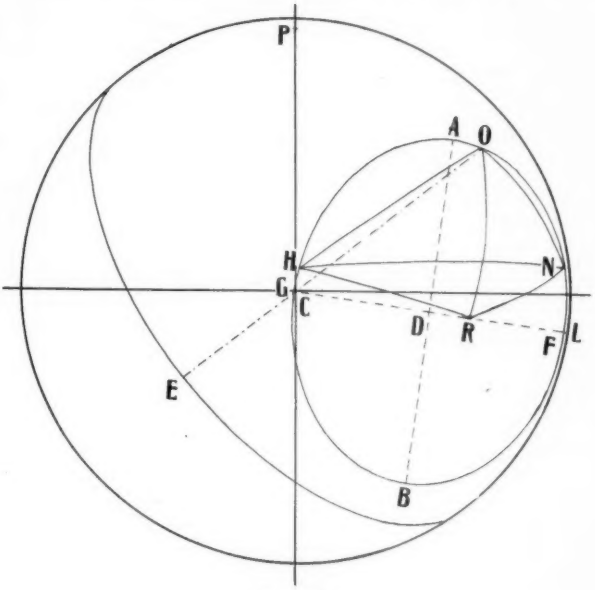

FIGURE 2.

CD, that is the known distance of the line from the center, must be equal to $\sin\phi'$, and $90 - \phi'$ must be the polar distance, or simply, the radius, of the circle which is drawn on the sphere about the point L as pole. The radius of the circle in its own plane is, of course, $\cos\phi'$. The pole L is evidently where the line CD produced cuts the large circle, and as its position angle q is known and ζ is equal to 90°, formula 14 will tell us that $N = 90°$, and $\sin\phi = \eta\cos\delta$, and $\cos\tau = \tan\delta\tan\phi$, where δ has its original value and ϕ and τ will locate the point L on the sphere. The length of the line ADB, which is twice AD on Fig. 2 or may be another known length, may be called ξ' and put equal to $\cos\phi'\sin\tau'$. In this equation we know ξ' and ϕ' and can thus find τ' or the length of the arc of the small circle whose projection is the straight line AD. It is evident that this arc will be the sum or difference of two arcs according as the points A and B on Fig. 2

are on opposite sides of CL or on the same side. It is also evident that the line ADB will become a great circle or a part of it if it passes through the center C.

2. To transfer a circle from the plane to the sphere. If the circle on the fundamental plane has its center at the point C, it will remain a circle when transferred to the surface of the sphere, its pole will be known at once, and its polar distance will be the arc whose sine is the radius of the circle on the plane. But if the circle on the fundamental plane has its center at any other point, the only way to transfer it will be by the general method of the following paragraph.

3. In order to transfer a plane figure of any kind to the surface of the sphere, the general method is to select as many of its points as may be necessary or desirable, translate their plane coördinates ξ and η or ζ and q into the spherical ones ϕ and τ by means of the equations given in Part I, and then connect these transferred points by arcs of great circles which, we may suppose, will contain all intermediate points. In this way the umbral and penumbral circles or lines of the Moon, Mercury and Venus, may be transferred from the fundamental plane to the Earth's surface and maps may be made which will show the visibility, times of beginning and ending, times and magnitudes of maximum obscuration, and the like, of a solar eclipse, of an occultation or of a transit of an inferior planet. In this method the only part that is graphic is the connection of the transferred points. If an entirely-graphic method is wanted, it may be found in Popular Astronomy, Nos. 32,33,34.

2. From the Sphere to the Plane.

1. Let it be proposed to draw an arc of a great circle about a given point as pole, and to project this arc upon the fundamental plane. If P on Fig. 1 is the given pole, the great circle is the equator, whose projection is an ellipse such that its semi-major axis is equal to the radius of the sphere or unity, its semi-minor axis is $\sin \delta = CE = \cos PC$, and its center is at the center of the sphere. If any other point such as O is given, the corresponding ellipse will have the same center and the same major axis as the equatorial one, and its semi-minor axis will be $\cos OC = \cos \zeta$ of the point O, and will, of course, lie upon the line OC produced. See Fig. 2.

2. To draw an arc of a small circle with a given radius (or polar distance) about a given point as pole. This problem is similar to that of constructing the ellipse of a parallel of lati-

tude whose semi-major axis $RD = a = \cos\phi$ on Fig 1, semi-minor axis $SD = b = \cos\phi \sin\delta$, and distance of center from center of sphere $CD = d = \sin\phi \cos\delta$. Hence if R on Fig. 2 is to be the pole, and the small circle is to pass through O, $a' = \cos\phi' = \cos(90 - OR) = \sin OR = AD$, $b' = \cos\phi' \sin\delta' = \sin OR \cos CR = GD$, and $d' = \sin\phi' \cos\delta' = \cos OR \sin CR = CD$. (In this practical example shown on Fig. 2 the points G and C happen to be very close, they are not coincident, but lie however on the same straight line $GCDRL$).

3. To draw an arc of a great circle through two given points. If P and O on Fig. 1 are the given points, the arc in question is part of a meridian ellipse, whose semi-major axis, like that of the projection of every great circle, is equal to unity, whose semi-minor axis $= B = \cos\delta \sin\tau$, and whose major axis makes an angle α with CP such that $\tan\alpha = \tan\tau \sin\delta$. Hence if an arc of a great circle is to be drawn through O and R on Fig. 2, we must take one point, such as O, as the pole, when its δ' will be equal to $90 - OC = 90 - \zeta$, and then find the spherical angle τ' or COR. Hence in this case $B' = \cos\delta' \sin\tau' = \sin OC \sin COR$, and $\tan\alpha' = \tan\tau' \sin\delta' = \cos OC \tan COR$, the angle α' being measured from OC.

4. To draw a circle through three given points, H, O, N. From the known latitudes and longitudes, or latitudes and hour angles, of the three points, we find the sides and angles of the triangle of which they are the vertices. The radius of the circle circumscribed about the triangle is next computed, and then the position of the pole. After this work has been done, the problem is the same as the one treated in No. 2.

In the practical example shown in Fig. 2 the three points selected were Omaha, O, ($\phi = +41° 16'$, $\lambda = +95° 57'$), Honolulu, H, ($\phi = +21° 19'$, $\lambda = +157° 52'$), and Panama, N, ($\phi = +8° 57'$, $\lambda = +79° 31'$). The radius of the circumscribed circle was found to be $39° 29'$, and its pole was located in $\phi = +7° 43'$ and $\lambda = +119° 25'$. The time selected for the projection was 10:25 p.m., central time, on March 2, 1906, when α Tauri reappeared in Omaha after having been occulted by the Moon. These data gave the constants of the ellipse $a' = AD = 0.636$, $b' = GD = 0.492$, $d' = CD = 0.488$, and $q = PCL = 97° 52'$. If the reader is interested in such projections he will find this same triangle HON in another projection, together with its polar triangle, its circumscribed and inscribed circles and other connected items, in the June number of School Science and Mathematics of this year.

5. If an irregular figure, such as the outline of a continent, is to be projected, we must have recourse to the method of points, project them individually and connect the projected points by a smooth curve.

Creighton University, Observatory.
Omaha, Nebraska.

THE SOURCE OF THE SUN'S HEAT.

J. F. LANNEAU.

FOR POPULAR ASTRONOMY.

Doubtless the Sun is receiving now more expert attention than any other single object in the material universe.

The world's telescopes daily confront it. At the Solar Observatory in Washington it is questioned almost hourly by Langley's exquisitely sensitive bolometer, sensitive to the one-millionth part of a centigrade degree.

At Williams Bay, with the Yerkes' forty-inch telescope and Hale's marvelous spectroheliograph, its entire disk is photographed day by day, giving a permanent record of changes in the spots and faculæ of the photosphere, and of the slow or rapid mutations in both the quiescent and the eruptive prominences of the chromosphere.

On Mt. Wilson near Los Angeles, California, is a veritable Sunbeam Laboratory—the unique Solar Observatory of the Carnegie Institute. It is a long, low, multiple-walled, canvas structure.

At one end a great clock-controlled heliostat steadily reflects sunbeams horizontally to the far-end mirror which returns them to its distant focus, forming there an exceptionally large, well defined image of the Sun. This faithful image can be patiently scrutinized the day long, and its every detail permanently mapped by a five-foot spectroheliograph—the largest yet constructed.

ESTABLISHED FACTS

Since Galileo's embryo telescope, three centuries of persistent effort have built a secure scaffolding for intelligent approach to the distant Sun—a scaffolding of established facts.

1. The Sun's parallax is now known to within two-hundredths of a second, its apparent diameter to within two seconds.

These measurements show that its diameter is 109½ times the Earth's diameter; and that its distance from us is not quite ninety-three million miles.

2. Since the volumes of globes compare as the cubes of their diameters, the Sun is more than a million times larger than this Earth. In mass or weight however it is only three hundred thirty-two thousand times greater. Its density therefore, is only one-fourth of the Earth's—or not quite one and a half times the density of water.

3. Gravity at the surface of a globe depends on its mass divided by the square of its radius. At the Sun's surface therefore, gravity is nearly twenty-eight times greater than gravity at Earth's surface. That is, if a common brick here weighs seven pounds, on the sun it would weigh two hundred pounds. A brick there would weigh as much as a barrel of flour here!

Look again at these facts.

The Sun's size:—a vast globe more than three-fourths of a million miles in diameter. From its center to its surface is nearly twice the distance from the Earth to the Moon!

The Sun's mass: its immense volume, as shown later, is a seething body of commingling gases—a great globe of glowing gas!

Expanding gas, growing larger and larger? Not at all. The expansive force lessens as the surface temperature is lowered by the cold of outer space; and it is checked also by the continuous inward pull of gravity. At a certain distance from the center, therefore, the outward and inward forces just counterbalance, giving definite size and boundary to the vast solar globe of gas.

"Light as gas?" Yes, but increase quantity and weight increases. Double, treble, multiply quantity, and weight is doubled, trebled, multiplied. The sun-globe of gas weighs as much as a third of a million worlds like ours.

The Sun's distance: ninety three million miles.

Our best modern, rifled artillery will throw a ball a half-mile in one second. At that rate a cannon ball will go thirty miles a minute; in an hour, 1800 miles; in a day, over 40,000 miles, in a month, more than one and a quarter million miles, and keeping an undeviating course sun-ward with unslaked speed, the so swift cannon ball would not quite reach the Sun in six years!

At that unthinkable remoteness, we yet feel here its panting July heat. There, yonder—beyond the swift missile's six years' flight—at the Sun, on its hot surface, how hot?

NATURE OF HEAT

Facts in regard to the Sun's heat have been reached slowly because of peculiar difficulties due to the nature of heat.

It is not, as once held, the fourth form of elementary matter—

earth, water, air, fire—nor yet, the subtile matter, "caloric", of a century ago. Indeed, though intimately associated with all forms of matter, heat itself is not matter.

It is force—energy—the force or energy of the constituent particles of either solids, liquids, or gases when the particles are in rapid motion—in minute, invisible, intense vibration. Matter may be opaque or transparent. We perceive its heat by the sense of touch. Heat is recognized not visually, but palpably. It is felt. As the feeling of warmth is the effect of the intense, invisible activity of the constituent particles of matter, so that of coldness results from their inactivity—their stillness.

Every hot body tends to coldness because its hedged-in multitudes of agitated particles, by the resistance of their recurring collisions, gradually settle toward rest.

Meanwhile, the molecular vibrations, imparted to the adjacent all-pervading ether, are transmitted radially to distant bodies, communicating vibratory motion to their particles. Thus a cold body may receive radiated heat from a distant hot body.

Air waves bring us the musical vibrations of a distant bell, and its pleasing sounds are reproduced in our aural nerves.

Ether waves bring us the vibrations of a distant hot body, and its heat is reproduced in our tactile nerves.

Usually heat is produced in either of two ways, mechanically or chemically. The heat of combustion in a wood or coal fire, or in a candle, is produced by the avidity of the oxygen particles of the air for the constituent particles of the fuel. Their clashings in chemical union cause that atomic commotion which constitutes the heat of the fire or of the candle flame—heat produced chemically.

Hammer vigorously a cold anvil. Both anvil and hammer become hot. The checked energy of the descending hammer is reproduced in the invisible commotion of the iron's particles. Energy of mass is transformed into energy of molecules, into heat, heat produced mechanically.

Force, like matter, is indestructible. This is the gist of the broad physical law of the conservation of energy. If any force is seemingly annulled, Proteus-like it reappears in a new form—or it is stored for future delivery.

The mechanical power of Niagara's water becomes in the shaft's crowning dynamo electric power, and that electric power at Niagara becomes in distant Buffalo light energy, or heat energy, or again motive power.

From yonder far off hot Sun comes radiated heat; from this,

our tropic and temperate heat, our wind and water power, and plant and animal energy; indeed all terrestrial activity—from the modest up-peep of tiniest grass-blade, to the proud coursing high over continents and seas of the coming air-ship!

AMOUNT OF SUN'S HEAT

The elder Herschel was the first to investigate the universe of stars and nebulæ. His illustrious son in 1838 took the first well directed step in the study of the Sun's heat. A sunbeam of known section, imparting its heat to a definite weight of water, raising its temperature an observed number of degrees, in a certain length of time, gave the coveted fundamental data: namely, the amount of heat received on a square foot of surface in one minute—taking as a unit of heat, the heat which raises a pound of water one degree Fahrenheit.

He found that the heat received at the Earth from the Sun in the zenith, is sufficient to melt an inch thick layer of ice in two hours and thirteen minutes. That is, if an inch thick shell of ice encompassed the Sun, distant from its center in all directions ninety-three million miles, that immense, remote ice shell would all be melted in two hours and thirteen minutes.

With Young, our highest authority on solar facts, fancy such an inch thick shell of ice kept intact and drawn inward toward the Sun, all the while containing the same quantity of ice, becoming thicker as it lessens in size. When it touches the Sun's surface, its thickness will exceed one mile.

That vast, solid glacier embracing the Sun, at every point over one mile high, would all be melted by the Sun's heat in two hours and thirteen minutes. It would melt a layer about forty feet thick each minute!

All honor to Herschel's conception and achievement. His method was perfect, but not his instruments. Better means now prove that the Sun radiates from its entire surface in one minute enough heat to melt encasing ice sixty-four feet thick!

TEMPERATURE OF THE SUN

Within experimental limits Stephan's thermal law holds, namely that the rate of heat radiation is as the fourth power of the absolute temperature. Assuming it to hold universally, this law and the known rate of the Sun's radiation—500 thousand units of heat per minute from each square foot of solar surface—give as the Sun's surface temperature 12,000° F, about sixty times the temperature of boiling water!

With much more certainty, a lower limit to the Sun's surface temperature has been found experimentally. Scheiner by ingenius use of the spectroscope, comparing lines of the solar spectrum with certain lines of magnesium, proved that the photosphere is hotter than the electric arc—that is, that its temperature is certainly above 7000° F. So also, the heat at the focus of a powerful lens has furnished a lower limit in a very realistic way.

The Sun's rays received on a lens or burning-glass are converged to its focus, producing at that point a high temperature. A point out in space to which the Sun's rays naturally converge at an angle equal to the focusing angle of the lens, may be termed the space-point of equal temperature. Its distance from the Sun is easily found, for the ratio of that distance to the focal length of the lens is the known ratio of the Sun's diameter to the lens' diameter.

At the focus of the largest lens yet constructed the high temperature produced instantly melted and vaporized the most refractory materials—platinum, fire-clay, carbon—everything tested. Its space-point of equal temperature is about two hundred fifty thousand miles from the Sun's surface—a little further from the Sun than the Moon is from us.

If then, our solid Earth were placed at that distance from the Sun—a quarter of a million miles—it would quickly melt, vaporize, vanish! That certainly is the temperature at one-fourth of a million miles from the Sun. Still higher is it at the Sun's surface—and inconceivably higher, the internal temperature.

SOURCE OF THE HEAT

How does the Sun produce its enormous output of heat, and maintain its inconceivably high temperature? Of four theories to be considered—if the newest suggestion can be called a theory—only one is perfectly satisfactory.

1. The Cooling Theory

It is certain the Sun is not simply an intensely hot body slowly cooling, for in that case, its materially lowered temperature after thousands of years of human history would have caused decided climatic changes, but we know that the vine the olive and the palm are fruitful now just where they flourished in the days of classic writers.

2. The Combustion Theory

It is equally certain that the Sun is not simply burning up—that its heat does not result from ordinary combustion. As estimated by Young, its continuous great yield of heat could be pro-

duced by the consumption every hour of a layer of coal all over the Sun's surface nineteen feet deep. That is, by burning one ton of coal hourly on each square foot of the Sun's surface.

Lord Kelvin computes that were its vast mass solid coal environed by pure oxygen, and yielding its heat by combustion, it would be utterly consumed in five thousand years. It would then, have dwindled more than one-third since Ptolemy's day. Yet, in the nearly two thousand years elapsed, it has certainly not diminished appreciably.

3. The Radium Theory

Though not produced by combustion, the Sun's heat is now surmised by some to be due largely if not entirely to radium—that most remarkable of known substances, discovered less than eight years ago by Mme. Curié. Proofs of its properties are ably presented in Rutherford's "Radio-Activity". It is not only self-luminous, but it is also self-heating, giving out every hour enough heat to melt more than its own weight of ice, a fourth more. It seems to be a very rare element. Tons of pitchblende yield only a few grains of radium. As radium evolves helium, and helium is known to be a chief component of the Sun's chromosphere, it is suggested that the Sun contains much radium.

Recall that the Sun radiates from its entire surface in one minute enough heat to melt encasing ice sixty-four feet thick. With this measure of the Sun's heat, and radium's heat emission per minute—melting one forty-eighth of its own weight of ice—as data, we readily find * that the Sun's heat equals the heat emitted by a mass of pure radium weighing nearly as much as the whole Earth weighs. That much of this rare and peculiar element in the Sun—our world's weight of radium—would yield its known output of heat.

The surmise that such a quantity of radium is there, rather segregates the Sun from common matter. Moreover, the properties of radium are none too well known. At present therefore, attributing the Sun's heat to radium, is simply an interesting speculation.

4. The Mechanical Theory

There remains for consideration, the mechanical origin of solar heat—that is, the conversion of force, or the energy of moving matter into heat energy. There can be no doubt that many millions of meteoric bodies are hourly falling into the Sun. We know that something like twenty million so-called shooting stars

* See note at end of article.

plunge into our atmosphere daily. Their checked energy of motion reappears in the air as light and heat. But the heat thus imparted to our Earth in a year has been shown † to be less than we receive from the Sun in one second! Incomparably more of such meteoric bodies are continually plunging into the solar at mosphere. Nevertheless, they must contribute comparatively little to the Sun's heat, for while interplanetary space, at least as far out as the Earth's orbit, is threaded by a veritable maze of meteoroids, if sufficiently more numerous throughout inner space to produce by their incessant impacts on the Sun a large part of its heat, the comparative density of the outlying myriads would affect perceptibly not only the periodic comets but also the planet Mercury. No such effects have developed.

Helmholtz's theory of the mechanical origin of solar heat—his contraction theory announced in 1853—fully accounts for the Sun's heat. Recall that the inward pull of gravity at the Sun's surface is nearly twenty-eight times gravity at the Earth's surface. Abundant evidence furnished by the spectroscope, and the Sun's known low density not much greater than that of water force the conclusion that the Sun is a vast sphere of commingling gases, among which many of our known vaporized terrestrial elements have been unmistakably identified.

As the Sun contracts by its own powerful gravitation, the potential energy lost by gradual inward motion is replaced by equivalent heat energy. Every particle in the whole stupendous mass moving inward, contributes to the Sun's inconceivable aggregate of heat. Helmholtz computed that an annual contraction of two hundred feet in the Sun's diameter is sufficient to produce the heat it radiates. More accurate recent measurements of the amount of heat radiated, indicate a greater contraction—a lessening of the Sun's diameter by three hundred feet annually. This even, is so slight a change in that diameter of near a million miles that in seven thousand years it will not appreciably alter the Sun's apparent breadth. Our present most exact heliometers could not then detect the change—a change in the Sun's angular breadth in seven thousand years of less than a single second! But as the Sun is a gaseous mass, its expanding force just counterbalanced by its gravitating force, it can contract only as its expanding force lessens by loss of heat radiated. Will it not then cool as it contracts? Not necessarily, for Lane's law, discovered about 1870, asserts the paradox that a globe of

† Physics of Shooting Stars, Pop. Astron. No. 128.

gas contracts by its own gravity and grows hotter, as necessary results of its loss of heat by radiation.

To illustrate:

Let v = volume of a globe of gas; p = its surface gravity, or pressure; and t = its absolute temperature. When from loss of heat by radiation its radius contracts one-half, let v', p', t' represent respectively its changed volume, pressure, and temperature. Since volumes compare as their radii cubed, and surfaces as radii squared, v' will equal $\frac{1}{8}v$, and the surface of v' will $= \frac{1}{4}$ the surface of v. Since surface gravity increases as the square of the radius diminishes, the inward pull or pressure on the surface of v' will $= 4$ times what it was on the surface of v; and as just shown, the surface of v' is only one-fourth that of v. Therefore, as a 4 times greater force will be exerted on a 4 times smaller surface, on a unit of surface the force or pressure on v' is 16 times the former pressure on v. That is, $p' = 16p$.

Moreover, Mariotte's well-known law requires that for a body of gas: The product of its volume and pressure changes as its temperature changes.

$$\begin{aligned} \text{Hence,}\quad & v \times p : v' \times p' :: t : t', \\ \text{or,}\quad & v \times p : \tfrac{1}{8}v \times 16p :: t : t', \\ \text{or}\quad & 1 : 2 :: t : t', \\ \text{or}\quad & t' = 2t. \end{aligned}$$

Thus, when contracted to half its radius the globe of gas is twice as hot as at the outset. In general, as it radiates heat it contracts, and as it contracts it grows hotter.

If, then, our Sun is truly gaseous from center to surface, notwithstanding its vast output of heat it must, by contraction, continually grow hotter. If however, as is likely, the photosphere of incandescent clouds of carbon droplets and the central density have made it partly viscous, or partly liquid, or even semi-fluid, then the heat produced by contraction may just equal that lost by radiation. In this case, the Sun's temperature will be constant—as probably it has been during the historic past.

With increased condensation, the heat of contraction will fail to replace that lost by radiation, and the Sun's temperature will lower more and more until it becomes cold, solid, dark!

When by contraction its present diameter is reduced one-half, its density will be increased eight-fold. It will doubtless be non-gaseous and will be cooling. Contracting still, cooling more, radiating less and less heat, it must finally fail to support any of the present forms of terrestrial life—the world we know will be dead!

It is somewhat comforting to learn from Newcomb and other eminent authorities that this sad failure of our now glorious Day-Star, when its generous heat and light shall be quenched—our world's night of death—is probably distant in the future some ten million years!

NOTE.

To find the mass of radium whose heat equals that of the Sun:

It has been established that the Sun radiates from its entire surface in one minute enough heat to melt encasing ice 64 feet thick. The volume of this enveloping crust of ice = the Sun's surface $\times$ 64 feet = $4\pi(433250)^2 \times \frac{64}{5280}$

cubic miles = $\frac{4\pi(433250)^2 \times \frac{64}{5280}}{\frac{4\pi}{3}(3959)^3}$ times the Earth's volume = .109998 times the Earth's volume.

The density of water = 1, that of ice = .92, that of earth = 5.55. The weight of the enveloping ice, therefore, = .92 of .109998 times weight of the Earth's volume of water = .92 of .109998 times $\frac{\text{The Earth's weight}}{5.55}$ =

.018234 times the Earth's weight.

But one gram of radium* yields each hour 100 calories of heat—gram calories.

Since 80 gram calories will melt one gram of ice, 100 calories will melt $^5/_4$ grams of ice. Thus the heat yielded by any mass of radium will melt per hour $^5/_4$ of its weight of ice, or per minute $^1/_{48}$ of its weight of ice.

As just shown, the Sun's heat at its surface would melt in one minute .018234 times the Earth's weight of ice. This weight of ice is $^1/_{48}$ of the weight of radium which would yield the heat to melt it.

That is, a mass of radium yielding the Sun's heat would weigh 48 times .01823, or .875 of the Earth's weight.

The remark, p. 415, "that such a quantity of radium (our world's weight of radium) is there, rather segregates the Sun from common matter" was based on the seeming rarity of terrestrial radium. But even with that bulk of radium diffused in the Sun, it would be a comparatively rare element there, for it would form but a trifling proportion of the Sun's immense mass, 332 thousand times the Earth's. It would be less than one three-thousandth part of one per cent of the Sun's substance. This allows the radio-active Sun more than a 99 per cent kinship with "common matter".

If then the Sun contains the world's weight of radium; if that supply is unwasting; if radium's rate of heat emission has been correctly determined; if that rate is maintained indefinitely; then, the Radium Theory of solar heat is indeed the simplest and most satisfactory. So constituted, the Sun's radiated heat would be at once replaced by the radium supply and the expanding and contracting forces would remain always equipoised. There would be no lessening of the Sun's diameter, no solar condensing, no cooling, no darkening, no night of death for our beautiful world—no change in the Sun, or under the Sun. But those four formidable Ifs! Possibly they may, in due time, be rightfully replaced by unqualified assertions. Meanwhile, Helmholtz's Contraction Theory is likely to remain the only entirely satisfactory one, in complete accord with established laws and observed facts.

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* Rutherford's Radio-Activity, p. 159.

THE SYSTEMATIC MOTIONS OF THE STARS AND THE GALAXY.

W. H. S. MONCK

FOR POPULAR ASTRONOMY.

Three years ago I suggested in the columns of POPULAR ASTRONOMY, that the discovery of the true direction of the Sun's motion in space was rendered difficult by systematic motions among the fixed stars, which were due at least in part to the position of the Galaxy. Prof. Kapteyn had, I believe, previously made similar remarks, of which I was then unaware; but he has since gone into the subject in greater detail, using the Catalogue of Bradley, compared with recent observations instead of that of Bossert, which I used. Bradley's Catalogue, which embraces about two-thirds of the sky, was no doubt intended as a complete list of the brighter stars to be seen within the limits in which he observed them, while Bossert's is a catalogue of stars with large proper motion: so that if two catalogues based on such different principles lead to similar results, the universality of these results (except in the case of very faint and motionless stars) may be inferred reasonably.

The Galaxy is usually regarded as a ring; and this theory may very possibly be correct, notwithstanding what I am about to remark. If a ring it would probably revolve, the different stars revolving with greater or less velocity according to their distance from the center of the ring, while the stars in the northern portion of the ring, for instance, would appear to be moving in an opposite direction from those in the southern portion. Two great star-streams directed to diametrically opposite points, both situated in the Galaxy, would thus at first sight seem to be accounted for. When we proceed to examine the details of Prof. Kapteyn's discovery, this explanation completely fails us. He finds both star-streams in every part of the sky though not always in the same proportion. Each half of the Galaxy contains a number of stars belonging to both streams, and it is near the Galactic Poles that one or other of the streams becomes enfeebled. What then is the meaning of two great streams of stars moving in diametrically opposite directions but both directed to points situated in the middle of the Galaxy—for the existence of two such streams seems to have been established by Kapteyn? All the stars, meaning, I presume, all those comprised in Bradley's Catalogue, belong in his opinion to one or the other of these streams.

But if so, must not the Sun himself belong to one of them? He can hardly be moving independently of the two great streams, to one or the other of which each of Bradley's 2500 stars belongs?

This consideration suggests to me a simpler theory, viz: that there is only one stream of stars directed towards a point in the Galaxy, of which stream the Sun is a member. The stars, which are moving with greater velocity than the Sun will appear to be moving towards this point, while those whose velocity is less than that of the Sun will appear to be moving towards a point diametrically opposite to it but also in the Galaxy. If this be the true explanation the Sun, besides partaking in the general Galactic motion, has a special motion of his own, just as the Sun carries the Earth and planets with him in his journey through space though each have special motions of their own round the Sun as center. This special motion of the Sun is perhaps caused by the attraction of his neighbors. His path may constitute an orbit, but if so it is probably a very wide orbit and does not differ much from a right line in the course of a century. The other stars I presume have their special motions also, while like the Sun they are carried along in the general motion of the Galactic stream.

If the Galaxy is really a ring, it is difficult to see how all the stars in it can constitute a single stream moving in a given direction. With a revolving ring it would only be possible if all Bradley's stars were on our side of the center of the ring; for those beyond the center would have an opposite motion. On this assumption the stars that are nearer to the center than we are would probably move with greater velocity than the Sun, while those that are farther from the center than we are would move with less velocity. But if all Bradley's stars are on this side of the center, the question arises whether we can see the far side of the ring at all? And may not the apparent ring-shape of the Galaxy be the result of prospective—of the projection of a star system whose real shape is quite different, on the celestial sphere?

Professor Kapteyn seeks to determine the two diametrically opposite points to which the two great star-streams appear to converge and it will be found that so far as Right Ascension is concerned they agree closely with the apex and ant-apex of the Sun's way. They are both situated in the middle of the Galaxy, and as the apex and ant-apex of the Sun's way are not in the Galaxy we cannot expect to meet with a closer correspondence than this; but I think the fact goes far to indicate that the Sun is a member of the general star-stream. The solar motion re-

solved in the direction of the Galaxy would I apprehend indicate the direction in which the great Galactic stream (on my hypothesis) is moving. This resolved motion would seem to be directed to the point supposed to be diametrically opposite to ξ Orionis but which Professor Kapteyn has not been able to fix accurately by examining the observed motions of the stars. While both of the two great star-streams moving in opposite directions seem to converge to a point, he remarks, "For one set the approximation is a very good one; for the other it is only tolerable. A better approximation, however, was not to be expected in this case, because the proper motions on which it rests are far smaller, consequently far less rigorously determined by observation." This looks as if the Sun were a comparatively fast-moving star; but a different explanation seems to me not unlikely. In examining Bossert's Catalogue I found that the change of increasing to diminishing Right Ascensions took place abruptly between the 6th and 7th hours of R. A., while at the second neutral point there was no abrupt change and the point where the preponderance of increasing Right Ascensions gave place to a preponderance of Right Ascensions could not be exactly defined and seemed moreover to be more than 12 hours distant from the defined neutral point between 6^h and 7^h R. A. Bradley's Catalogue, though the stars are selected on a different principle from Bossert's, seems to present the same feature and I think the most natural explanation of it is that these neutral points are mainly dependent on the Galaxy, which is narrow and well defined at one neutral point and diffused and even double at the other. This leads to the further remark that the two points to which Kapteyn's star-streams are directed agree very closely as regards Right Ascension with the apex and ant-apex of the Sun's way. One point is well defined and the other badly defined (owing to the shape of the Galaxy near the point in question); but on my hypothesis of a single Galactic stream, it is towards the undefined point that this stream is directed. I should state, however, that in speaking of a single stream I only mean that the stars are all moving, roughly speaking, in the same direction. There may be two branches of the Galaxy whose courses are similar to that of a river running around an island—the river separating into two branches at the head of the island and meeting again at the foot of it; or to make the parallel more exact, we might suppose the island to be submerged with a shallow stream flowing over it in the same direction as the two main branches of the river. All this is speculation, but I think the current notions as to figure

of the Galaxy will have to be considerably altered.

The solar motion I apprehend consists of two points—a motion along the Galaxy which is common to the Sun and to all the stars whose motions are measurable, and what I may call an orbital motion depending most probably on the attraction of the Sun's nearest neighbors which is not in the direction or even the plane of the Galaxy and requires separate investigation, whereas what we have hitherto sought to ascertain is the resultant of this double motion. Something similar might be said even if the existence of Kapteyn's two distinct Galactic streams moving towards opposite goals were established; for if all the stars in the Bradley Catalogue belong to one or the other of the streams, it is natural to conclude that the Sun does so likewise; and the determinations of his path already made seem to leave no doubt as to which stream he belongs. Our computations must therefore, I think in any event be recast. We have to deal with a double motion, not a single motion.

It must not be forgotten however that all that can be observed is relative motion and that therefore what we take to be systematic motions among the fixed stars may not impossibly be accounted for by hitherto unobserved movements within the solar system itself. It has been maintained for instance that the diurnal rotation of the Earth is gradually becoming slower owing to tidal friction. If this be so the duration of the sidereal year, *as measured in days, hours, minutes and seconds* is becoming shorter; and at the end of what is supposed to be the sidereal year, all the stars are slightly in advance of their true places. Other causes within the solar system could also be mentioned, the effects of which might simulate systematic movements in the stars. In order to ascertain the true movements in R. A. and Decl., of any star we have to make several corrections in our actual observations, and none of these can be asserted to be absolutely free from error. Before we can affirm positively that there is any systematic movement among the stars—whether generally or limited to those comprised in a particular Catalogue—we should ascertain that the observed motions of the stars could not be caused by any motions in the solar system. If the Galaxy resembles a long straight tube stretching from the apex of one of Kapteyn's streams to that of the other after which its course is practically rectilinear, we would expect to find the Galactic stars much more dense at these two points than elsewhere and also to find a brighter background. I am not aware that this is so. In any event it might be safe to ascertain the proper motion of stars

which have perceptible proper motion by comparison with faint and apparently motionless stars, than by measures by R. A. and Declination. Photography will much assist this mode of ascertaining motion of this kind.

Finally let me remark that if what I have called the Sun's orbital motion does not take place in a plane at right angles to the Galaxy it will be difficult to discriminate between its orbital and galactic motions; for the orbital motion resolved in the direction of the Galaxy will increase or diminish the velocity of the Galactic motion. We can only approximate. For reasons that I have already suggested I think the R. A. of the apex of the Sun's way (as usually computed) is largely dependent on his Galactic motion, and perhaps might be reversed by reducing the velocity of this motion without altering its true direction. But, if the stream tends towards a point whose declination is southern while the apex of the Sun's way has clearly a northern declination, the Sun must have a well marked motion independently of the Galaxy which we may be able ere long to trace in a more satisfactory manner.

A SIMPLE METHOD OF OBTAINING AN APPROXIMATE SOLUTION OF KEPLER'S EQUATION.*

ARTHUR A. RAMBAUT.

In the *Monthly Notices*, vol. l. p. 301, I have described a method of solving Kepler's equation, viz:

$$m = u - e \sin u,$$

by means of a prolate trochoid.

Six years later the same method was described by Mr. Plummer in the *Monthly Notices*, vol. lvi. p. 317, but no question of priority need arise, as the principle of the method is 200 years older than either of us, being contained in the thirty-first proposition of the first book of Newton's *Principia*.

The object of the present note is to point out another way in which the solution may be very simply effected by the help of the involute of the circle.

Let us take a circle, AMB, fig. 1, with center C and any radius AC, and lay off the arc AM corresponding to the angle m. From M draw portion of the involute MVT, which can be done very

* MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY, June, 1906.

accurately by mechanical means. Divide AC at F so that $\frac{FC}{AC}=e$. From F draw a tangent to the involute at V cutting the circle in P and Q. Then the angle AFV = u.

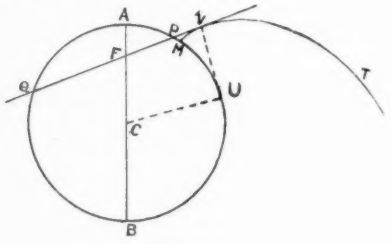


FIGURE 1.

For the normal to the involute at V touches the circle at U where the radius CU is parallel to the tangent FV. But

$$AM = AU - MU = AU - VU = AU - FC \sin ACU,$$

or dividing by the radius,

$$m = ACU - \frac{FC}{AC} \sin ACU$$

Hence ACU = AFV = u.

Now if the circle be graduated and numbered from 0° at A through P to 180° at B, and also from 0° at B through Q to 180° at A, the arcs AP and BQ may be read off directly, and we have

$$AU = \tfrac{1}{2}(AP + BQ)$$

Hence by taking the mean of the readings of the circle at the points P and Q, where it is cut by the tangent to the involute, we obtain the value of u. It may also be remarked that if u_0 is an approximate value of u thus obtained, and if m_0 be computed from the expression*

$$m_0 = u_0 - e \sin u_0$$

we have

$$\Delta u = \frac{m - m_0}{1 - e \cos u_0}$$

Δu being the correction of the first order required by u_0. But if the radius of the circle be taken as unity we have

$$FV = 1 - e \cos u_0$$

Hence

$$\Delta u = \frac{m - m_0}{FV}$$

* Compare Dr. See's paper entitled "A General Method for Facilitating the Solution of Kepler's Equation by Mechanical Means," *Monthly Notices*, vol. lv. p. 425.

The frontispiece is a reproduction of a photograph of a very simple instrument constructed on the above principle, by which the value of u may be obtained to within one-tenth of a degree in elliptic orbits of any eccentricity.

For this instrument I have adapted a small setting circle taken from the old "Jones" Meridian Circle of the Radcliffe Observatory. This circle is 5.5 inch in diameter, and is very neatly divided to half-degrees on silver. As the graduations are not numbered, as suggested above, but run continuously through 360°, it is necessary to subtract 90° from the mean of the readings at P and Q in figure 1.

The instrument has been constructed for me by a skilful watchmaker—Mr. H. Minn, of Oxford. The involute is cut out of a plate of ebonite, and seems to be very accurate in figure. The radius is divided to hundredths on a thin silvered plate screwed on to the face of the circle. The tangent is represented by a fine string winding around the involute, passing across the face of the circle and kept taut by a small weight which hangs over the edge of the brass plate, supported on three feet, which forms the base of the instrument.

With this apparatus a first approximation to u in ellipses of any eccentricity can be found with great rapidity. The advantages it seems to possess are: (1) the involute can be drawn very accurately by means of a string, or watch-spring, coiled round a cylinder; (2) a very small portion of the involute is required, only so much of it, in fact, as corresponds to a radian in the circle; (3) all angles are read off on the circle, which may be divided with any degree of accuracy required.

It would be unbecoming of me if in praise of this instrument I were to indulge in the enthusiastic language which Dr. See bestows on Waterson's Curve of Sines method (see *Monthly Notices*, vol. lvi. p. 54). I hope, however, that Dr. See may be induced to give this new method a trial, and in that case I shall be disappointed if he does not come to prefer it to any other.

DR. EDMOND HALLEY AND HIS COMET; A REFERENCE LIST.

(Supplementing previous lists published in POPULAR ASTRONOMY, xiii., 471, 579-580,.) Compiled by Eugene Fairfield McPike.

A complete life of Dr. Halley, by an English astronomer, is now in prospect (1906).

Bibliographies, etc. of Dr. E. Halley:

Forsyth, A. R. An appreciation of Halley. (In the *Observatory*, 28, no. 363 [Nov. 1905]: 405-407.)

General index to Dodsley's Annual register, from its commencement in 1758 to the year 1819. London: Baldwin, Cradock & Joy, 1826. VI, 938 pp.

Contains (p. 305) several references to Dr. E. Halley.

McPike, Eugene Fairfield. Dr. Edmond Halley (In *Notes and Queries*, London, tenth series, 4, no. 105 [Dec. 30, 1905]: 526-527.)

A reference list supplementing a series published in the same periodical.

McPike, Eugene Fairfield. Halleiana inedita. (In the *Observatory*, 29, no. 368 [March, 1906]: 137-138.)

A reference list of unpublished material.

McPike, Eugene Fairfield. Extracts from British archives . . . (In the *Magazine of History with notes and queries*, New York, 3, No. 3 [March 1906]: 176-181.)

To be continued: Contains some new biographical material concerning Dr. E. Halley.

Halley's Comet.

Astronomische Nachrichten, begründet von H. C. Schumacher. Unter Mitwirkung des Vorstandes der Astronomischen Gesellschaft herausgegeben. With supplements. Kiel, 1823.

Present editor, 1906, Prof. H. Kreutz, Kiel. Contains many notes on Halley's comet.

Carl, Philip Franz Heinrich. Repertorium der Cometen Astronomie. München: Rieger, 1864. vi, 378 pp. 8°.

Not examined; no copy in the John Crerar Library, Chicago, nor in the Library of Congress, Washington. From the latter was obtained the specific notice above given, "found in Kayser's Bücher-Lexikon." The "Repertorium," according to private advices from Prof. H. Kreutz, of Kiel, contains an extensive list of references (page 369 ff) to the literature of Halley's comet.

Halley's comet. (In the *Penny Magazine*, Sept. 12, 1835: page 360.)

Quotes an account by Professor Airy, originally printed in the *Cambridge Chronicle*, pertaining to an observation "by a well-known observer, near Bromley, in Kent." Mentions, also, an account in the London *Times*, of an observation by Sir James Smith, at Kensington.

Lynn, W[illiam] T[hynne.] Perihelion distance of Halley's comet. (In the *Observatory*, 29, no. 366 (Jan. 1906): 67-68.)

PLANET NOTES FOR SEPTEMBER AND OCTOBER, 1906.

H. C. WILSON.

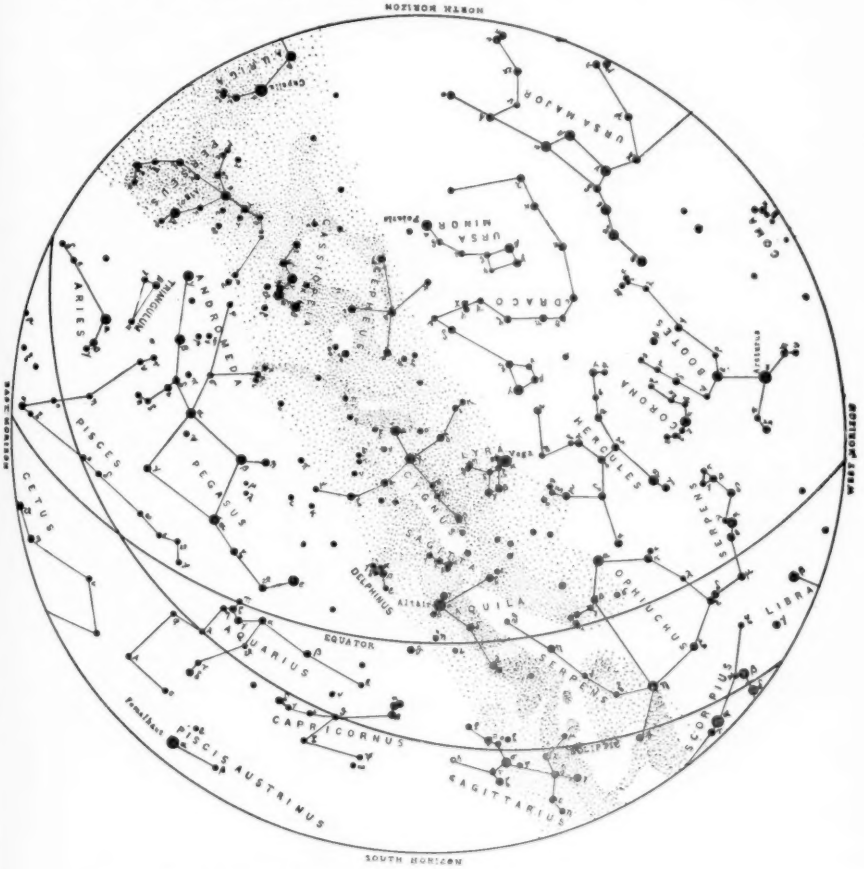
Mercury is morning star, visible in the east in the morning just before sunrise, for the first few days of September. It comes to superior conjunction September 23 and will not be visible again to the naked eye until the last days of October when it will be evening star visible in the west just after sunset.

Venus will be at greatest elongation, east from the Sun 46° 29′, on September 20, and may be seen as a brilliant star in the west in the early part of the evening. The phase of the planet is diminishing, being slightly gibbous September 1, just half full September 17, and crescent thereafter. The brightness of the planet on the other hand is rapidly increasing and will reach its maximnm in the last days of October.

Mars is on the farther side of the Sun and so is not favorably placed for ob-

servation. Mars and Mercury will be in conjunction in right ascension and only 9′ apart in declination on September 4, at 8 p. m. central time.

Jupiter will be at quadrature, 90° west from the Sun, October 3 and so may be observed in the morning during these months.



THE CONSTELLATIONS AT 9:00 P. M. OCTOBER 1, 1906.

Saturn will be at opposition September 4. These two months are therefore the best of this year for the study of the ringed planet. Saturn is in the constellation Aquarius, seen toward the south at midnight and is brighter than any of the stars in the vicinity so that it is easily recognized with the naked eye. The angle which the plane of Saturn's rings makes with our line of sight is small this year, increasing from 4° 48′ September 1 to 6° 21′ October 31, so that the details of structure of the rings will be difficult to see.

Uranus is past the best position for this year, but may be observed in the

early evening. With the aid of a small telescope, the planet may be found in the constellation Sagittarius. It is moving slowly eastward about 2° north of the star λ Sagittarii. Uranus will be at quadrature, 90° east from the Sun, Sept. 28.

Neptune will be at quadrature, 90° west from the Sun, December 6, and may be observed in the morning with the aid of a telescope in the constellation Gemini.

Occultations Visible at Washington.

Date 1906.	Star's Name	Magnitude.	IMMERSION. Washington M T.	Angle f'm N pt.	EMERSION. Washington M.T.	Angle f'm N pt.	Duration.
			h m	°	h m	°	h m
Sept. 1	ι Aquarii	4.4	7 49	30	8 41	300	0 52
1	42 Aquarii	5.5	14 36	27	15 30	284	0 54
10	119 Tauri	4.9	11 49	113	12 34	216	0 45
25	33 Sagittarii	5.8	5 39	126	6 48	235	1 09
25	ξ^2 Sagittarii	3.7	7 49	74	9 07	274	1 18
27	19 Capricorni	5.7	8 17	9	8 53	319	0 36
27	21 Capricorni	6.5	11 44	41	12 43	280	0 59
29	70 Aquarii	6.1	12 09	25	13 09	281	1 00
Oct. 4	μ Ceti	4.3	8 48	19	9 32	294	0 44
8	χ^3 Orionis	5.1	10 37	66	11 36	271	0 59
8	68 Orionis	5.7	15 55	147	16 37	199	0 42
10	B. A. C.2605	6.2	13 30	83	14 39	274	1 09
22	Bradley 2332	5.7	5 44	78	7 01	276	1 17
27	ψ^1 Aquarii	4.5	4 50	105	5 50	212	1 00
29	26 Ceti	6.0	13 51	94	14 53	217	1 02
31	ξ^2 Ceti	4.3	6 58	108	7 47	201	0 49

Phases of the Moon.

	C. S. T.			C. S. T.		
		h	m		h	m
Full Moon	Sept. 2	5	36	Oct. 1	18	48
Last Quarter	10	2	53	9	21	39
New Moon	17	18	33	17	4	42
First Quarter	24	12	11	23	19	50
Full Moon				31	10	45

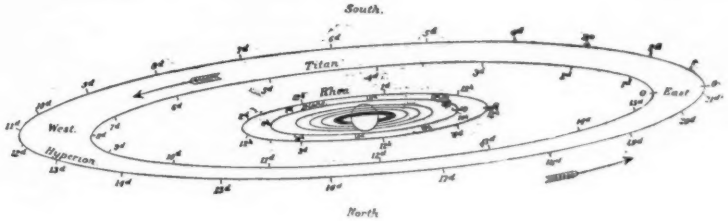
The Satellites of Saturn.

Apparent orbits of the seven inner satellites of Saturn as seen in an inverting telescope.

Central Standard Time reckoning from noon.

I. Mimas. Period 0^d $22.^h6$.

	h		h		h		h
Sept. 1	8.8 W	Sept. 14	13.4 W	Oct. 1	12.4 W	Oct. 19	10.1 W
2	7.4 W	15	12.0 W	2	11.0 W	20	8.7 W
4	15.9 E	16	10.6 W	3	9.6 W	21	7.3 W
5	14.6 E	17	9.2 W	4	8.3 W	26	11.7 E
6	13.2 E	18	7.9 W	9	12.9 E	27	10.4 E
7	11.9 E	22	13.6 E	10	11.3 E	28	9.0 E
8	10.4 E	23	12.2 E	11	9.9 E	29	7.6 E
9	9.0 E	24	10.8 E	12	8.5 E		
10	7.6 E	25	9.4 E	17	12.9 W		
14	14.9 W	26	8.0 E	18	11.5 W		



II Enceladus. Period 1^d $8.^h9$.

Sept.	1	14.7 E	Sept.	16	16.3 E	Oct.	1	18.0 E	Oct.	16	19.7 E
	2	23.5 E		18	1.2 E		3	2.9 E		18	4.6 E
	4	8.4 E		19	10.1 E		4	11.7 E		19	13.4 E
	5	17.3 E		20	19.0 E		5	20.6 E		20	22.3 E
	7	2.2 E		22	3.8 E		7	5.5 E		22	7.2 E
	8	11.1 E		23	12.7 E		8	14.4 E		23	16.1 E
	9	19.9 E		24	21.6 E		9	23.3 E		25	1.0 E
	11	7.8 E		26	6.5 E		11	8.2 F		26	9.9 E
	12	13.7 E		27	15.3 E		12	17.0 E		27	18.7 E
	13	22.6 E		29	0.2 E		14	1.9 E		29	3.6 E
	15	7.5 E		30	9.1 E		15	10.8 E		30	12.5 E

III Tethys. Period 1^d $21.^h3$

Sept.	1	11.4 E	Sept.	16	13.8 E	Oct.	1	16.1 E	Oct.	16	18.5 E
	3	8.7 E		18	11.1 E		3	13.4 D		18	15.8 E
	5	6.0 E		20	8.4 E		5	10.7 E		20	13.1 E
	7	3.3 E		22	5.6 E		7	8.0 E		24	7.8 E
	9	0.6 E		24	2.9 E		9	5.3 E		26	5.1 E
	10	21.9 E		26	0.2 E		11	2.6 E		28	2.4 E
	12	19.2 E		27	21.5 E		12	2.39 E		29	23.7 E
	14	16.5 E		29	18.8 E		14	21.2 E		31	21.0 E

IV Dione. Period 2^d $17.^h7$.

Sept.	3	11.8 E	Sept.	17	4.0 E	Oct.	3	14.0 E	Oct.	17	6.3 E
	6	5.4 E		19	21.7 E		6	7.7 E		20	0.0 E
	8	23.1 E		22	15.4 E		9	1.3 E		22	17.7 E
	11	16.7 E		25	9.0 E		11	19.0 E		25	11.4 E
	14	10.4 E		28	2.7 E		14	12.7 E		28	5.0 E
				30	20.3 E					30	22.7 E

V Rhea. Period 4^d $12.^h5$.

Sept.	4	21.5 E	Sept.	18	10.4 E	Oct.	1	23.5 E	Oct.	15	12.5 E
	9	9.8 E		22	22.8 E		6	11.8 E		20	0.9 E
	13	22.1 E		27	11.1 E		11	0.2 E		24	13.3 E
										29	1.7 E

VI Titan. Period 15^d $23.^h3$.

Sept.	4	16.0 W	Sept.	20	13.6 W	Oct.	2	14.0 I	Oct.	18	11.9 I
	8	11.5 S		24	9.1 S		6	11.4 W		22	9.4 W
	12	12.9 E		28	10.6 E		10	6.9 S		26	5.1 S
	16	16.3 I					14	8.5 E		30	6.6 E

VII Hyperion. Period 21^d $7.^h6$.

Sept.		6.0 E	Sept.		21.6 S	Oct.		3.3 I	Oct.		18.3 E
		12.2 I			27.2 E			8.3 W			24.5 I
		17.2 W						12.8 S			29.5 W

VIII Iapetus. Period 79^d $22.^h1$.

Sept.		6.3 S	Sept.		25.3 E	Oct.		15.0 I	Nov.		4.2 W

Elements and Ephemeris of Jupiter's Seventh Satellite.— In *A.N.* 4101 Mr. Frank E. Ross, of the International Latitude Observatory at Gaithersburg, Md., gives the following elements and ephemeris of Jupiter's seventh satellite.

1906 Jan. 0.0 Gr. M. T.	Elements referred to Earth's equator.
$g = 18.°9$	$e = 0.208$
$\pi = 118°$	$n = 1.°386$
$\Omega = 291°$	$\log a = 8.8946$
$i = 25° 28'$	Period = 259.7 days.

"This satellite is only slightly more distant from Jupiter than the sixth, about two per cent or 170,000 miles. On account of their large eccentricities however, they do not approach within two million miles of each other. The mutual inclination of their orbits is 28.°1."

EPHEMERIS FOR GREENWICH MEAN MOON.

1906		p	s	1906		p	s	1907		p	s
		°	′			°	′			°	′
Aug.	15	223	9	Nov.	8	98	45	Jan.	27	307	58
	20	183	10		13	94	42	Feb.	1	305	61
	25	158	13		18	89	38		6	304	63
	30	144	18		33	84	34		11	302	64
Sept.	4	136	24		28	76	30		16	300	65
	9	131	29	Dec.	3	66	26		21	299	66
	14	127	33		8	51	23		26	297	65
	19	123	38		13	32	21	Mar.	3	296	64
	24	121	42		18	11	22		8	295	62
	29	119	44		23	353	25		13	294	59
Oct.	4	117	46		28	340	29		18	292	56
	9	115	48	1907					23	291	52
	14	112	49	Jan.	2	330	34		28	289	48
	19	110	50		7	323	39	Apr.	2	287	43
									7	284	38
	24	108	50		12	318	44		12	281	32
	29	105	49		17	313	49		17	277	27
									22	270	21
Nov.	3	102	47		22	310	54		27	257	16

COMET AND ASTEROID NOTES.

Definitive Elements of Comet 1883 I.—In *A. N.* 4090 Mr. Emil Hellebrand gives the results of a definitive determination of the orbit of the Comet 1883 I, which was observed February 24, to April 9, 1883. He finds that the observations are best satisfied by an hyperbolic path with eccentricity 1.0003439, but that a parabola represents them almost equally well. He adopts as definitive the elements of the parabola.

$T = 1883$ Feb. 18.990481 Berlin M. T.
$\omega = 110° 54' 35''.13$
$\Omega = 278 08 11 .16$
$i = 78 03 39 .63$
$\log q = 9.8808490$

Finlay's Periodic Comet Discovered.—A cablegram from Kiel, Germany, received July 18, through the courtesy of Harvard College Observatory, announces the discovery of Finlay's periodic comet by Kopff at Heidelberg on July 16. The approximate position taken from a photograph was July 16.527 Gr. M. T., R. A. = $23^h 38^m 20^s$; Decl. $-14° 03'$.

This gives a correction to the ephemeris computed according to Schulhof's

elements of $-12^m\ 11^s$ in R. A. and $-1°\ 37.'5$ in Decl. on July 16. The perihelion will accordingly be about September 8.35 instead of September 7.3.

The comet was looked up at Goodsell Observatory on the night of July 20. It was easily seen with the five inch finder but was rather faint and diffuse; about 5′ in diameter, nearly round and had but little central condensation. In the 16-inch telescope it was also about 5′ in diameter, with a weak central condensation and a nucleus of about the twelfth magnitude. The coma extended a little farther toward the west than toward the east.

The calculated brightness of the comet was greatest about August 9. In September it will be about the same as in July.

Elements of Finlay for 1906.—In *A.N.* 4106 Mr. L. Schulhof gives elements of this periodic comet, based upon the observations at the two apparitions in 1886 and 1893, and corrected for the perturbations of the planets up to this present year. In 1899 and 1900 the comet was unfavorably situated with reference to the Sun. This year it is much more favorably placed and will be easily seen.

The following are the most probable elements determined by Schulhof:

Epoch 1906 Aug. 1.0 Paris M. T.

$M = 354°\ 22'\ 45.''7$ $\quad \phi = 46°\ 23'\ 22.''9$

$\pi = 8\ 10\ 55.\ 2$ $\quad \mu = 542.''557$

$\Omega = 52\ 22\ 37.\ 7$ $\quad$ 1906.0 $\log a = 0.815560$

$i = 3\ 03\ 05.\ 5$ $\quad$ T = Sept. 7.3 Paris M. T.

Ephemeris of Comet Finlay (1906 *d*)

1906		α app. h m s	δ app. ° ′ ″	log Δ	aberr. m s	1 : $r^2\,\Delta^2$
Sept.	1	5 39 51.23	+16 36 35.2	9.54783	2 56	8.53
	2	44 55.44	16 53 32.1	55539	2 59	
	3	49 51.61	17 9 28.9	56289	3 2	8.00
	4	54 40.05	17 24 28.7	57032	5	
	5	5 59 21.07	17 38 34.4	57767	8	7.50
	6	6 3 54.95	17 51 49.0	58494	12	
	7	8 21.99	18 4 15.2	59211	15	7.03
	8	12 42.44	18 15 55.5	59919	18	
	9	16 56.55	18 26 52.5	60616	21	6.59
	10	21 4 56	18 37 8.6	61302	24	
	11	25 6.70	18 46 45.9	61978	28	6.18
	12	29 3.18	18 55 46.6	62642	31	
	13	32 54.20	19 4 12.8	63295	34	5.79
	14	36 39.94	19 12 6.2	63936	37	
	15	40 20.56	19 19 28.7	64564	40	5.43
	16	43 56.23	19 26 21.9	65180	43	
	17	47 27.11	19 32 47.6	65784	47	5.09
	18	50 53.33	19 38 47.3	66375	50	
	19	54 15.03	19 44 22.5	55954	53	4.78
	20	6 57 32.34	19 49 34.6	67521	56	
	21	7 0 45.36	19 54 25.0	68075	3 59	4.49
	22	3 54.21	19 58 54.9	68617	4 2	
	23	6 59.01	20 3 5.6	69147	5	4.22
	24	9 59.85	20 6 58.3	69664	8	
	25	12 56.83	20 10 34.2	70169	11	3.97
	26	15 50.02	20 13 54.2	70662	14	
	27	18 39.51	20 16 59.5	71142	17	3.74
	28	21 25.38	20 19 51.1	71610	19	
	29	24 7.68	20 22 29.9	72067	22	3.52
	30	26 46.47	20 24 57.0	72512	25	
Oct.	1	7 29 21.82	+20 27 13.3	9.72945	4 27	3.32

Naming of Asteroids.—The following names have been assigned by Mr. P. Götz of Heidelberg to minor planets discovered by him:

(538)	[1904 OK]	Friederike	(556)	[1905 PW]	Phyllis
(545)	[1904 OY]	Messalina	(563)	[1905 QK]	Suleika
(547)	[1904 PB]	Praxedis	(564)	[1905 QM]	Dudu
(548)	[1904 PC]	Kressida	(567)	[1905 Q P]	Eleutheria.

VARIABLE STARS.

Variable RV (136.1904) Ophiuchi.—A letter from Mr. Raymond S. Dugan of the Halsted Observatory at Princeton N. J. states that "Minima of RV Ophiuchi (136.1904) observed here April 18, May 3 and May 14 compared with Ceraski's observation 1904 Aug. 22, make the period $3^d.687$. Epoch 1906, May $3^d\ 17^h.7$ Gr. M. T.

The entire light change occupies about 10 hours, constant minimum light lasting about 1½ hours. Entire range is 2 magnitudes

Ephemeris of Minima (Gr. M. T.)

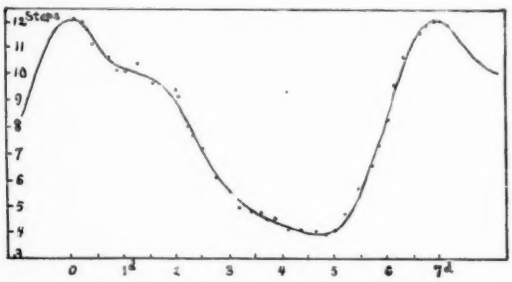
1906 May	22^d	4^h	1906 June	13^d	7^h
	25	21		17	0
	29	13		20	16
June	2	6		24	9
	5	22		28	1
	9	15	July	1	17"

Note:—This variable was discovered by Mrs. Fleming and announced in Circular 80. From the observed minima, the formula $2416604^d.7396+3.6872$ E was deduced. Observations by Professor Wendell on 15 nights, including three series at times of minimum show that there is a secondary minimum of about one tenth of a magnitude and that the variable is of the β Lyrae type.

E. C. PICKERING.

Harvard College Observatory,
Cambridge Mass.
May 21, 1906.
Astronomical Bulletin No 244.

Light Curve of U Aquilæ.—In *A.N.* 4097 Mr. M. Luizet gives 361 observations of this variable made by himself during the years 1898-1905. The observations afford 78 maxima and 69 minima. He determines new elements



THE LIGHT CURVE OF U AQUILÆ.

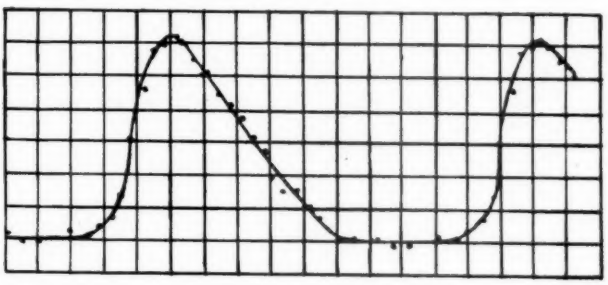
by combining his own observations with those of Sawyer, Yendell and Hisgen, obtaining in Paris mean time

Maximum 2410170.321 ± 0.^{d}135
Minimum 2410168.031 ± 0. 081 } + (7.^{d}02387 ± 0.00019) E

or Maximum 1886 Sept. 20 7^h 56^m
Minimum 1886 Sept. 18 0 45 + (7^d 0^h 34^m 22^s) E.

The light curve is shown in the accompanying cut. From this it will be seen that the increase of light is very regular, occupying about 2.20 days, while the decrease is slower and irregular, taking about 4.82 days. The extreme magnitudes are 6.2 and 6.9 on the scale of the Harvard Photometry.

Elements and Light Curve of the Variable 76.1905 Cygni.—In *A. N.* 4094 Mr. Sigurd Enebo gives new elements and a light curve of the star 76.1905 Cygni, determined from a large number of observations extending from December 16, 1905 to February 27, 1906. The range of variation is from 8.68



Light Curve of 76.1905 Cygni.

to 9.30 magnitude. At minimum the light is constant for about three hours, then the increase is very rapid, the maximum short and the decrease slower than the increase of light. The elements are

Max. 1905 Dec. 21 6^h 06^m.0 Gr. M. T. + 0^d 11^h 11^m 51^s.0 E.
= J. D. 2417201.25417 + 0^d.46654 E.

The following comparison stars were used by Mr. Enebo:

	BD.	Mag.	R. A. 1855	Decl. 1855
	°		h m s	° ′
a	+55 2219	9.0	19 29 51	+55 43.8
b	+56 2269	9.2	19 30 48	+56 20.2
c	+56 2256	9.5	19 29 11	+56 16.3
d	+55 2222	9.4	19 30 42	+55 51.3
e	+55 2226	8.6	19 32 44	+55 38.8

New Variable 40.1906 Geminorum.—In *A. N.* 4092 Mr. Sigurd Enebo of Dombaas, Norway, calls attention to the star BD + 26° 1412 which appears to vary between magnitudes 9.1 and 9.5 in a period of something like two years. The position of the star is

For 1855.0 R. A. 6^h 50^m 32^s.39 Decl. + 26° 14′ 10″.6
For 1900.0 R. A. 6 53 19 .50 Decl. + 26 10 47 .8

New Variable 54.1906 Draconis.—This was found by Mme L. Ceraski on the Moscow photographs May 23. Its position is

1855.0 $\alpha = 12^h\ 31^m\ 12^s$ $\delta = +66°\ 23.'6$
1900.0 $12\ 33\ 11$ $+66\ 08.7$

The light apparently varies between 9.7 at maximum and below 12½ at minimum.

Twenty-Two New Variable Stars in Carina.—In Harvard College Observatory Circular 115 Professor Pickering announces 22 new variables, found by Miss H. S. Leavitt in a re-examination of six photographs of the southern constellation Carina, upon which ten variables had already been found at a preliminary examination. In *A.N.* 4102 these 22 variables are numbered from 55.1906 to 76.1906. The region containing them extends from $10^h\ 17^m$ to $10^h\ 57^m$ in R. A. and from −57° to −62° in Declination. All but four of them are below the 10th magnitude.

A New Algol Star 73.1906 Carinæ.—One of the variables mentioned above was suspected by Miss Leavitt of being of the Algol type. Accordingly its image was examined upon 137 photographs. On 16 of these it was found to be fainter than the normal magnitude 12.25. The observations are satisfied very closely by adopting, for the times of minimum,

J. D. 2410001.53 + $3.^d30070$ E.

The position of this star for 1900.0 is

R. A. = $10\ \ 54^m\ 11^s$; Decl. = $-61°\ 22.'9$.

The magnitude at minimum is about 12.8.

Approximate Magnitudes of Variable Stars on August 1, 1906.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

The letter *i* denotes that the light is increasing, the letter *d* that the light is decreasing, the sign <, that the variable is fainter than the appended magnitude.

The magnitudes given have been compiled by Mr. Leon Campbell of the Harvard College Observatory, from observations made at the Vassar College, Whiteside, and Harvard Observatories.

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R.A. 1900. h	m	Decl. 1900. °	′	Magn.
T Androm.	0	17.2	+26	26	8.0 *i*	R Aurigae	5	9.2	+53	28	10.5*d*
T Cassiop.		17.2	+55	14	8.0 *i*	V Camelop.		49.4	+74	30	12.2*d*
R Androm.		18.8	+38	1	9.0*d*	X Aurigæ	6	4.4	+50	14	9.0
U Cassiop.		40.8	+47	43	11.5 *i*	Y Draconis	9	31.1	+78	18	11.5 *i*
RR Androm.		45.9	+35	50	11.5 *i*	R Leonis		42.2	+11	54	9.2*d*
W Cassiop.		49.0	+58	1	9.0	V Leonis		54.5	+21	44	13.3*d*
S "	1	12.3	+72	5	8.5 *i*	R Urs. Maj.	10	37.6	+69	18	13.0*d*
RU Androm.		32.5	+38	10	10.0 *i*	S Leonis	11	5.7	+ 6	0	12 *i*
U Persei		52.9	+54	20	9.0*d*	R Comae		59.1	+19	20	9.5*d*
R Arietis	2	10.4	+24	35	8.0	RX Virginis		59.6	− 5	13	8.5
Z Cephei		13.0	+81	13	<12	RW "	12	2.1	− 6	12	8
o Ceti		14.3	− 3	26	9.0*d*	R Corvi		14.4	−18	42	9.0 *i*
S Persei		15.7	+58	8	9.3*d*	T Can. Ven.		25.2	+32	3	12.5*d*
RR Cephei		29.4	+80	42	<12	Y Virginis		48.7	− 3	52	8.7 *i*
T Camelop.	4	30.4	+65	57	13.0*d*	RS Urs. Maj.		34.4	+59	3	<12
X "		32.6	+74	56	8.5*d*	T Urs. Maj.		31.8	+16	2	8.5

Approximate Magnitudes of Variable Stars on Aug. 1, 1906.
(Continued.)

Name.	R. A. 1900.	Decl. 1900.	Magn.	Name.	R. A. 1900.	Decl. 1900.	Magn
	h m	° ′			h m	° ′	
R Virginis	12 33.4	+ 7 32	8.6*d*	RZ Herculis	18 32.7	+25 58	<12
S Urs. Maj.	39.6	+61 38	12.0*d*	X Ophiuchi	33.6	+ 8 44	8.3*d*
RU Virginis	42.2	+ 4 42	11.0*d*	RY Lyrae	41.2	+34 34	<12
U "	46.0	+ 6 6	10.0 *i*	R Scuti	42.2	− 5 49	5.6
RV "	13 2.7	−12 38	11.5*d*	R Aquilae	19 1.6	+ 8 5	10.7*d*
R Hydrae	24.2	−22 46	6.0*d*	RX Sagittarii	8.7	+18 59	9.2 *i*
R Can. Ven.	44.6	+40 2	11.0*d*	RW "	8.1	−19 2	9.9*d*
Z Bootis	14 1.7	+13 58	<12	RS Lyrae	9.3	+33 15	12.2*d*
Z Virginis	5.0	−12 50	10.0 *i*	U Draconis	9.9	+67 7	9.0 *i*
S Bootis	19.5	+54 16	13.5	W Aquilae	10.0	− 7 13	<12
RS Virginis	22.3	+ 5 8	<12	T Sagittarii	10.5	−17 9	8.5
V Bootis	25.7	+39 18	8.0 *i*	R "	10.8	−19 29	12.5*d*
R Camelop.	25.1	+84 17	9.6 *i*	RY "	10.0	−33 42	7.5
R Bootis	32.8	+27 10	11.0 *i*	Z "	13.8	−21 7	10.5 *i*
U "	49.7	+18 6	12.0*d*	S "	13.6	−19 12	11
RT Librae	15 0.8	−18 21	12.0*d*	TZ Cygni	13.4	+50 0	11.5*d*
T "	5.0	−19 38	<12	U Lyrae	16.6	+37 42	8.8 *i*
Y "	6.4	− 5 38	12.5*d*	T Sagittae	17.2	+17 28	9.8*d*
S "	15.6	−20 2	9.6*d*	R Cygni	34.1	+49 58	11.8*d*
S Serpentis	17.0	+14 40	11.4 *i*	RV Aquilae	35.9	+ 9 42	10.5 *i*
S Coronae	17.3	+31 44	11.1*d*	RT Cygni	40.8	+48 32	9.0*d*
RU Librae	27.7	−14 59	11.0 *i*	TU "	43.3	+48 49	<12
S Urs. Min.	33.4	+78 38	8.7 *i*	χ "	46.7	+32 40	11.5*d*
R Coronae	44.4	+28 28	6.0	RR Aquilae	52.4	− 2 11	<12
— "	45.3	+37 49	14	RS "	53.7	− 8 10	11.7
V Coronæ	46.0	+39 52	10.5*d*	Z Cygni	58.6	+49 46	10.5 *i*
R Serpentis	46.1	+15 26	7.5*d*	R Capric.	20 5.7	−14 34	12.2
RR Librae	50.6	−18 1	10.5 *i*	S Aquilae	7.0	+15 19	11.7*d*
Z Scorpii	16 0.1	−21 28	11.3*d*	RU "	8.0	+12 42	12
R Herculis	1.7	+18 38	9.7*d*	W Capric.	8.6	−22 17	11.5
RR "	1.5	+50 46	8.5	Z Aquilae	9.8	− 6 27	12.0*d*
U Serpentis	2.5	+10 12	10.5*d*	RS Cygni	9.8	+38 28	8.5*d*
X Scorpii	2.7	−21 16	<12	R Delphini	10.1	+ 8 47	<12
W "	5.9	−19 53	<12	RT Capric.	11.2	−21 38	7.5*d*
RU Herculis	6.0	+25 20	13.5*d*	SX Cygni	11.6	+30 46	<11.5
R Scorpii	11.7	−22 42	<12	U "	16.5	+47 35	8.3 *i*
S "	11.7	−22 39	<12	RW "	25.2	+39 39	8.5
W Coronae	11.8	+38 3	14	RU Capric.	26.7	−22 2	12
W Ophiuchi	16.0	− 7 28	<12	S Delphini	38.5	+16 44	11.7*d*
V "	21.2	−12 12	7.5 *i*	V Cygni	38.1	+47 47	11.5 *i*
U Herculis	21.4	+19 17	9.8*d*	Y Aquarii	39.2	− 5 12	<12
SS "	28.0	+ 7 3	9.0 *i*	T Delphini	40.7	+16 2	10.5 *i*
S Ophiuchi	28.5	−16 57	<13	V Aquarii	41.8	+ 2 4	8.6*d*
W Herculis	31.7	+37 2	11.7*d*	W "	41.2	− 4 27	8.3 *i*
R Draconis	32.4	+66 58	12.3*d*	U Capric.	42.6	−15 9	12.3*d*
RR Ophiuchi	43.2	−19 17	8	V Delphini	43.2	+18 58	<12
S Herculis	47.4	+15 7	10.5*d*	T Aquarii	44.7	−5 31	12.3*d*
RV "	56.8	+31 22	10.0 *i*	RZ Cygni	48.5	+46 59	9.1*d*
R Ophiuchi	17 2.0	−15 58	10.7*d*	X Delphini	50.3	+17 16	8.5*d*
RT Herculis	6.8	+27 11	9	— "	50.3	+17 18	<12
RS "	17.5	+23 1	12.0	R Vulpeculae	59.9	+23 26	8.0 *i*
Z Ophiuchi	14.5	+ 1 37	9.2 *i*	V Capric.	21 1.8	−24 19	<12
RS "	44.8	− 6 40	10.8*d*	X "	2.8	−21 45	<12
RT "	51.7	+11 10	11.5	X Cephei	3.6	+82 40	9.5 *i*
RY Herculis	55.4	+19 29	<12	R Equulei	8.4	+12 23	9.5 *i*
T "	18 5.3	+31 0	9.0 *i*	T Cephei	8.2	+68 5	8.0*d*
W Draconis	5.4	+65 56	<12	T Capric.	16.5	−15 35	12
X "	6.8	+66 8	10.5	RR Aquarii	9.8	− 3 19	11.0 *i*
W Lyrae	11.5	+36 38	10.5*d*	Y Capric.	28.9	−14 25	<12
T Serpentis	23 9	+ 6 14	<12	S Cephei	36.5	+78 10	9.5 *i*

Approximate Magnitudes of Variable Stars on August 1, 1906.

(Continued)

Name.	R. A. 1900 h m	Decl. 1900 ° ′	Magn.	Name.	R.A. 1900 h m	Decl 1900 ° ′	Magn.
SS Cygni	21 38.8	+43 8	12.0	SPegasi 23	15.5	+ 8 22	10.0 *i*
T Lacertae	22 17.9	+33 52	10.0	Z Cassiop.	39.7	+56 2	<12
S "	24.6	+39 48	9.0	RR "	50.6	+53 10	12
R "	38.8	+41 51	<12	R "	53.3	+50 50	8.5*d*
R Pegasi 23	1.6	+10 0	9.5 *i*	Y "	58.2	+55 7	<12
V Cassiop.	7.4	+59 8	8.5 *i*				

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time. To reduce to Central Standard time subtract 6 hours, or for Eastern time subtract 5 hours.]

(Alternate minima only are given this month.)

U Cephei		RT Persei		R Canis Maj.		V Puppis		Z Draconis	
d	h	d	h	d	h	d	h	d	h
Sept. 1	12	Sept. 13	12	Sept. 12	10	Sept. 16	13	Sept. 2	3
6	11	15	5	14	16	19	11	4	20
11	11	16	22	16	23	22	9	7	13
16	11	18	14	19	5	25	7	10	6
21	10	20	7	21	12	28	4	12	23
26	10	22	0	23	18	Oct. 1	2	15	17
Oct. 1	10	23	17	26	1	4	0	18	10
6	9	25	10	28	7	6	22	21	3
11	9	27	2	30	14	9	20	23	20
16	9	28	19	Oct. 2	20	12	17	26	13
21	8	30	12	5	3	15	15	29	6
26	8	Oct. 2	5	7	9	18	13	Oct. 1	23
31	8	3	21	9	16	21	11	4	17
Z Persei		5	14	11	22	24	9	7	10
Sept. 1	11	7	7	14	5	27	7	10	3
7	14	9	0	16	11	30	4	12	20
13	17	10	17	18	18	S Cancri		15	13
19	20	12	9	21	1	Sept. 2	9	18	6
25	22	14	2	23	7	21	8	21	0
Oct. 2	1	15	19	25	14	Oct. 10	8	23	17
8	4	17	12	27	20	29	7	26	10
14	6	19	4	30	3	S Velorum		29	3
20	9	20	21	γ Camelop.		Sept. 5	21	31	20
26	11	22	14	Sept. 2	18	17	17	δ Libræ	
Algol		24	7	9	9	29	14	Sept. 1	5
Sept. 1	20	26	0	16	23	Oct. 11	11	5	21
7	14	27	16	22	14	23	8	10	13
13	8	29	9	29	5	RR Velorum		15	4
19	1	31	2	Oct. 5	19	Sept. 2	8	19	20
24	19	λ Tauri		12	10	6	1	24	12
30	12	Sept. 4	23	19	1	9	18	29	4
Oct. 6	6	12	21	25	15	13	11	Oct. 3	19
12	0	20	18	RR Puppis		17	4	8	11
17	17	28	16	Sept. 4	21	20	21	13	3
23	11	Oct. 6	14	17	18	24	14	17	18
29	5	14	11	30	14	28	7	22	10
RT Persei		22	9	Oct. 13	11	Oct. 2	0	27	2
Sept. 1	15	30	7	26	8	5	17	31	18
3	8	R Canis Maj.		V Puppis		9	10	U Coronæ	
5	0	Sept. 1	1	Sept. 2	0	13	3	Sept. 1	16
6	17	3	8	4	22	16	20	8	13
8	10	5	14	7	20	20	13	15	11
10	3	7	21	10	18	24	6	22	9
11	19	10	3	13	15	27	23	29	7
						31	16		

Minima of Variable Stars of the Algol Type.—Continued.

U Coronæ		Z Herculis		RX Herculis		U Sagittæ		W Delphini	
d	h	d	h	d	h	d	h	d	h
Oct. 5	4	Sept. 4	10	Sept. 19	15	Sept. 24	15	Sept. 22	23
12	2	8	10	21	9	Oct. 1	10	Oct. 2	14
19	0	12	10	23	4	8	4	12	5
26	21	16	10	24	23	14	22	21	19
R Aræ		20	10	26	17	21	17	31	10
Sept. 5	3	24	9	28	12	28	11	Y Cygni	
13	23	28	9	30	7	SY Cygni		Sept. 2	15
22	20	Oct. 2	9	Oct. 2	1	Sept. 1	15	4	2
Oct. 1	16	6	9	3	20	13	16	8	15
10	12	10	9	5	15	25	16	10	2
19	9	14	8	7	10	Oct. 7	16	14	15
28	5	18	8	9	4	19	16	16	2
U Ophiuchi		22	8	10	23	31	17	20	15
Sept. 1	14	26	8	12	18	WW Cygni		22	2
3	6	30	8	14	12	Sept. 1	19	26	15
4	23	RS Sagittarii		16	7	8	10	28	2
6	15	Sept. 1	17	18	2	15	2	Oct. 2	15
8	7	6	12	19	20	21	17	4	1
9	25	11	8	21	15	28	8	8	14
11	15	16	4	23	10	Oct. 5	0	10	1
13	8	21	0	25	4	11	15	14	14
15	0	25	20	26	23	18	6	16	1
16	16	30	16	28	18	24	21	20	14
18	9	Oct. 5	12	30	12	31	13	22	1
20	1	10	8	RR Draconis		SW Cygni		26	14
21	17	15	4	Sept. 3	0	Sept. 3	15	28	1
23	10	20	0	8	16	12	18	VV Cygni	
25	2	24	20	14	8	21	22	Sept. 1	5
26	18	29	16	20	0	Oct. 1	1	4	4
28	10	V Serpentis		25	16	10	5	7	3
30	3	Sept. 1	7	Oct. 1	8	19	8	10	2
Oct. 1	19	8	5	7	0	28	12	13	1
3	11	15	2	12	15	VW Cygni		15	23
5	3	22	0	18	7	Sept. 7	11	18	22
6	20	28	22	23	23	24	7	21	21
8	12	Oct. 5	20	29	15	Oct. 11	4	24	20
10	4	12	17	RV Lyræ		28	1	27	19
11	20	19	15	Sept. 3	15	UW Cygni		30	18
13	13	26	13	10	20	Sept. 3	11	Oct. 3	17
15	5	RX Herculis		18	1	10	8	6	16
16	21	Sept. 1	20	25	5	17	6	9	15
18	13	3	15	Oct. 2	10	24	4	12	14
20	6	5	9	9	15	Oct. 1	1	15	12
21	22	7	4	16	20	7	23	18	11
23	14	8	23	24	0	14	20	21	10
25	7	10	17	31	5	21	18	24	9
26	23	12	12	U Sagittæ		28	16	27	8
28	15	14	7	Sept. 4	9	W Delphini		30	7
30	7	16	1	11	3	Sept. 3	18	UZ Cygni	
		17	20	17	21	13	9	Sept. 11	10
								Oct. 12	17

Maxima of Variable Stars of Short Period not of the Algol Type.

The times of maxima only are given; the times of minima may be obtained by subtracting the interval printed in parentheses under the name of the star.

Maxima of Variable Stars of Short Period not of the Algol Type.

(Continued)

Y Aurigæ			T Velorum			S Crucis			S Normæ			U Sagittarii		
	d	h		d	h		d	h		d	h		d	h
	(−0	18)	Oct.	11	11	Sept.	21	1		(−4	10)		(−2	23)
Sept.	3	13		16	3		25	18	Sept.	3	20	Sept.	3	16
	7	9		20	18		30	10		13	14		10	10
	11	6		25	9	Oct.	5	3		23	8		17	4
	15	3		30	1		9	19	Oct.	3	2		23	22
	19	0		W Carinæ			14	12		12	20		30	16
	22	20		(−1	0)		19	4		22	14	Oct.	7	9
	26	16	Sept.	2	6		23	21	R V Scorpii				14	3
	30	14		6	14		28	13	(−1	10)			20	21
Oct.	4	10		10	23	W Virginis			Sept.	3	0		27	15
	8	7		15	8	(−8	5)			9	1	β Lyræ		
	12	3		19	17	Sept.	3	19		15	3		(−3	2)
	16	0		24	2		21	1		21	4		(−3	7)
	19	20		28	11	Oct.	8	8		27	6	Sept.	6	8
	23	17	Oct.	2	20		25	14	Oct.	3	7		13	1
	27	14		7	5	V Centauri				9	9		19	7
	31	10		11	14	(−1	11)			15	10		25	23
T Monocerotis				15	23	Sept.	5	8		21	11	Oct.	2	5
(−7	22)			20	7		10	20		27	13		8	21
Sept.	13	4		24	16		16	8	X Sagittarii				15	3
Oct.	10	4		29	1		21	20	(−2	21)			21	19
W Geminorum			S Muscæ				27	7	Sept.	6	0		28	1
(−2	16)		(−3	11)		Oct.	2	19		13	1	κ Pavonis		
Sept.	8	13	Sept.	8	18		8	7		20	1	(−4	7)	
	16	6		18	10		13	19		27	1	Sept.	2	21
	24	0		28	1		19	7	Oct.	4	1		12	0
Oct.	1	18	Oct.	7	17		24	19		11	2		21	2
	9	12		17	9		30	7		18	2		30	4
	17	5		27	1	R Triang. Austr.				25	2	Oct.	9	6
	24	23	T Crucis			(−1	0)		Y Ophiuchi				18	8
ζ Geminorum			(−2	2)		Sept.	1	7	(−6	5)			27	11
(−5	0)		Sept.	4	15		4	16	Sept.	6	1	U Aquilæ		
Sept.	9	23		11	9		8	2		23	4	(−2	4)	
	20	3		18	3		11	11	Oct.	9	7	Sept.	7	1
	30	6		24	20		14	20		26	10		14	2
Oct.	10	10	Oct.	1	14		18	6	W Sagittarii				21	3
	20	14		8	7		21	15	(−3	0)			28	3
	30	17		15	1		25	0	Sept.	7	11	Oct.	5	4
V Carinæ				21	18		28	10		15	1		12	4
(−2	4)			28	12	Oct.	1	19		22	16		19	5
Sept.	3	2	R Crucis				5	5		30	6		26	6
	9	19	(−1	10)			8	14	Oct.	7	20	U Vulpeculae		
	16	12	Sept.	2	8		11	23		15	10	(−2	3)	
	23	4		8	4		15	9		23	1	Sept.	2	3
	29	21		14	0		18	18		30	15		10	3
Oct.	6	14		19	20		22	3	Y Sagittarii				18	2
	13	7		25	16		25	13	(−2	2)			26	2
	19	23	Oct.	1	11		28	22	Sept.	1	9	Oct.	4	1
	26	16		7	7	S Triang. Austr.				7	3		12	1
T Velorum				13	3	(−2	2)			12	22		20	1
(−1	10)			18	23	Sept.	3	19		18	16		28	0
Sept.	4	9		24	19		10	3		24	11	SU Cygni		
	9	0		30	14		16	11		30	5	(−1	8)	
	13	15	S Crucis				22	19	Oct.	6	0	Sept.	2	9
	18	7	(−1	12)			29	2		11	19		6	5
	22	22	Sept.	2	7	Oct.	5	10		17	13		10	2
	27	13		6	23		11	18		23	8		13	22
Oct.	2	5		11	16		18	2		29	2		17	18
	6	20		16	8		24	9					21	15
							30	17					25	11

Variable Stars of Short Period not of the Algol Type.—Continued.

SU Cygni

	d	h
Sept.	29	7
Oct.	3	3
	7	0
	10	20
	14	16
	28	13
	22	9
	26	5
	30	2

η Aquilae (− 2 6)

Sept.	6	23
	14	3
	21	7
	28	11
Oct.	5	16
	12	20
	20	0
	27	4

S Sagittae (− 3 10)

Sept.	4	20

S Sagittae

	d	h
Sept.	13	5
	21	15
	30	0
Oct.	9	9
	16	18
	25	3

X Cygni (− 6 19)

Sept.	12	1
	28	11
Oct.	14	20
	31	5

T Vulpeculae (− 1 10)

Sept.	2	9
	6	19
	11	6
	15	16
	20	3
	24	13
	29	0
Oct.	3	10

T Vulpeculae

	d	h
Oct.	7	21
	12	7
	16	18
	21	4
	25	14
	30	1

WZ Cygni Minimum Period 14^h

Sept.	1	14
	3	22
	6	6
	8	14
	10	23
	13	7
	15	15
	17	23
	20	7
	22	15
	24	23
	27	9
	29	15

WZ Cygni

	d	h
Oct.	2	0
	4	8
	6	16
	9	0
	11	8
	13	16
	16	0
	18	8
	20	16
	23	0
	25	9
	27	17
	30	1

TX Cygni (− 5 3)

Sept.	1	6
	16	0
	30	17
Oct.	15	10
	30	4

VY Cygni

	d	h
	(− 2	2)
Sept.	1	4
	9	0
	16	21
	24	17
Oct.	2	14
	10	10
	18	7
	26	3

δ Cephei (− 1 10)

Sept.	5	15
	11	0
	16	9
	21	18
	27	2
Oct.	1	11
	7	20
	13	5
	18	14
	23	22
	29	15

A New Algol Variable 78.1906 Sagittarii.—In Circular 117 is announced another Algol variable discovered by the process of having a series of equal exposures made upon the same plate, the plate being shifted between the successive exposures. A photograph taken June 28, 1902 contains 13 exposures of 30 minutes each, and the images of the star in question show a gradual increase from 16.0 up to 8.7 magnitude. A similar photograph taken July 7, 1905 exhibits a like change in this star. From an examination of 304 photographs the period is determined to be a little over two days, the elements being approximately

$$\text{Minimum} = 2410001.980 + 2.^d07694\ E.$$

The star is Cordoba DM. − 30° 16169 and its position for 1875 is

$$\text{R. A.} = 18^h\ 38^m\ 04.^s2 \quad \text{Decl.} = -30°\ 37.'2$$

New Variables of the Algol Type 79.1906 Delphini.—In *A. N.* 4106 Professor W. Ceraski announces another Algol Variable, discovered by Mme L. Ceraski on the Moscow photographs.

The star is BD.+ 13° 4502 and its position is

1855	$\alpha = 20^h\ 36^m\ 44.^s6$	$\delta = +13°\ 25.'6$
1900	$= 20\ \ 38\ \ 51.\ 7$	$+13\ \ 35.\ 2$

Ordinarily the star is of magnitude 9.5 but at minimum it goes down to 10.5 and perhaps lower. The period and the character of the light curve are unknown.

GENERAL NOTES.

At the May meeting of the Columbia University Trustees, Mr. J. K. Rees, Rutherfurd Professor of Astronomy, and head of the Astronomical department was made a Professor *Emeritus*. Mr. Harold Jacoby succeeds Professor Rees; Dr. Charles Lane Poor will be associated with him as a Professor in the department, and Dr. S. A. Mitchell is promoted to an instructorship in Astronomy.

Father Hedrick at Georgetown College Observatory. Father Hagen is succeeded at Georgetown College Observatory since his departure for the Vatican Observatory, by Father Hedrick, who had been his associate for many years, his special line of work having been heretofore a large share of the computations and reductions at the observatory. His principal publication is a discussion of the photographic transits of one hundred sixty-one stars on fifteen nights.

Naked Eye Observation of Occultation of α Leonis (Regulus) May 2, '06. When boarding a train at Lathrop, California, this evening, my daughter, Miss Helen Dodge Hill, and myself—two San Francisco "refugees"—noticed the star Regulus very close to the dark (invisible) limb of the moon, and it was evident that an occultation was imminent. The night was very clear, and the train running very smoothly, so that it was possible to keep the star in sight right up to the moment of occultation. We both observed it to disappear sharply at $7^h 51^m 04^s$ by my watch.

Upon arrival at Modesto the watch was compared with the standard clock in the office of the W. U. Telegraph Company, viz:

Watch—$8^h 24^m 45.0^s$
Clock—$8^h 24^m 00.0^s$

The clock was $1^m 15^s$ slow at time, and the watch losing 9 seconds per hour, so that the record was made May 2, 1906, $7^h 51^m 29.5^s$, Pacific Standard Time. The place was two miles north of Ripon on the S. P. R. R., or in

Latitude: $+37° 14.'4$
Longitude: $121° 10.'0$ W

Of course, the observation has no scientific value, but I have thought it worth while recording, as a naked eye observation of the occultation of an anything but bright "first magnitude" star made from a rapidly moving railroad train! We may have earthquakes in California, but as certainly we can still claim climate!

Modesto, Cal. May 2, 1906. CHAS. B. HILL.

Dr. Roe's Observatory. A small private observatory, unique in its appointments and mechanically quite perfect in its construction, is being built this summer by Dr. Edward D. Roe, professor of mathematics at Syracuse University, purely for his own study and enjoyment.

From the *Syracuse Herald* we glean the following details:

A pier of solid mason work and concrete was started seven feet under ground at the rear of his house, as the center of an addition, 14 by 21 feet. To a distance of three feet above the surface the pier was built four feet square, the remainder of the distance of thirty feet to the top being three feet square. The capstone was hardened for about two weeks, then was placed the cast iron pillar, weighing 780 pounds, on which the telescope will rest. The square work of the observatory is 14 feet square surmounted with a 14-foot dome. The timber used is hemlock and kiln-dried pine. Although the dome is at an elevation of about forty feet from the ground, it is so constructed that the wind cannot possibly cause a vibration. If the track upon which the dome revolves by the touch of one's little finger should become elliptical its usefulness would be ended. Braces are run all the way down to the ground floor between the partitions, besides which there are eight guards to prevent the dome from rising. There is scarcely a chance of this contingency, however, because the action of the wind is such as to press the dome down in place. A galvanized iron cylinder runs around the bottom of the dome as still another safeguard against the action of the wind. A few days ago when

the wind was blowing at a velocity of forty miles an hour not the slightest motion in the air was perceptible from the observatory. The shutter, instead of opening sideways, slides back over the top of the dome and this arrangement on preliminary experiments has worked to perfection. A thousand feet of lumber were used in the three layers forming the track and rafters. The dome will revolve on eight pairs of rollers which Professor Roe himself designed, the inner wheels being an inch less in diameter than the outer to insure their running evenly. It has a six and one-half inch aperture and is nine feet long, equatorially mounted with two driving clocks, one that drives around the polar axis the other around the hour circle, with two slow movements operated at the eye end. There are six eyepieces ranging in power from 36 to 650 diameters. The latter size would bring the moon within 400 miles.

Physical Demonstration of Astronomical Principles. In an interesting letter received too late for publication in our last issue, Samuel Miller of Ilion. N. Y., refers to the physical demonstration of some astronomical principles in the following language:

"I have lately been very much interested in Prof J. T. Lovewell's experiments with the Foucault Pendulum at the Kansas Academy of Science, of which he has kept me informed; those experiments have gained additional interest by my being able, through the courtesy of a scientific friend in England, to compare them with some recently observed demonstrations of the great pendulum in South Kensington Museum, and to find such almost perfect agreement between these two tests so far removed from each other, thus establishing beyond all question the Earth's rotation, rouses my enthusiasm for attempting the physical demonstration of other important principles of our astronomical system.

We have another principle susceptible of demonstration and which I think is very desirable to demonstrate, as I consider it the great fundamental law on which the Copernican theory rests—Kepler's second law of planetary motion—'The radius vector of each planet describes equal areas in equal times.'

This law which superficially appears to be in opposition to the usual manifestations of centrifugal force and therefore offers a difficult problem to the student, should be, and I think may be, easily illustrated by either of two simple and inexpensive mechanical devices which I have in mind, and would be glad to send a detailed description to anyone who may wish to take up this interesting study."

On the Earthquake of April 18, 1906. It is not necessary to say that the earthequake of April 18th was very severe on Mount Hamilton, but it is a matter for congratulation that the observatory suffered no serious injury. Director Campbell was in Washington, D. C., at the time, and Astronomer Tucker was in charge. It was found that the telephone connection with San Jose was destroyed, and, as fires were observed to break out at once in San Jose and San Francisco, the seriousness of the situation was soon realized. Professor Tucker dispatched a bicycle messenger to San Jose, bearing the message that, "The buildings and instruments of the Lick Observatory were not injured by the earthquake." All was confusion in San Jose and there was no telegraph or telephone communication with the outside world. The messenger therefore rode on to Berkeley, 75 miles from Mount Hamilton, and delivered a copy of the message to President Wheeler of the University, late in the afternoon of the 18th. As it was not possible to send private dispatches, the message was delivered to the Associated Press with the request that it be sent over the wires as soon as possi-

ble. This was done on the 19th, and the message was correctly published in many eastern papers of the 20th. A Chicago paper containing it overtook me in Iowa on the forenoon of the 20th, as I was speeding westward, and the relief afforded will not soon be forgotten. It was hoped that this information would reach all inquiring friends of the observatory, both in this country and abroad, but there soon appeared to be considerable doubt of this. On this account the message was at our request repeated a week later by the Associated Press.

The details of the earthquake are given for Mount Hamilton in Mr. Madrill's note. The maximum double amplitudes of the motion here could scarcely be less than, and perhaps exceeded, three inches. Fortunately, the period of vibration was long, and the buildings and instruments apparently had time to follow the Earth motions. The tops of three large and one small brick chimneys were cracked, but not broken off. A great many old cracks in plastering were reopened, and many new cracks were formed. These apparently comprise the damage on the mountain. The brick and cement reservoirs and the water systems were not affected. Professor Tucker's observations with the meridian circle established that the instrument's position had not shifted appreciably. At my request, Dr. Aitken and Dr. Moore determined the position of the polar axis of the 36-inch refractor. They found no significant change.

This immunity, so to speak, is somewhat surprising, in view of the fact that the damage in San Jose, only thirteen miles directly west of us, was severe, and that in regions thirty to fifty miles east of us a large proportion of chimney tops were thrown down. Altitude alone can scarcely be a protective factor. The breaks in the rock strata between this observatory and the origin of disturbance —there are two narrow valleys between us and San Jose—are probably potent factors in reducing intensities. It is a familiar fact that earth waves of great destructiveness on one side of a mountain range often reappear destructively on the other side, as in the present case, with only minor destruction in the mountains themselves; but the explanation of these phenomena is usually not apparent. There can be no doubt, however, that the rigid rock foundations of our buildings and instruments were exceedingly important elements in their stability, under the severe strains suddenly thrown upon them.

The indirect effects of the catastrophe upon the finances of the Lick Observatory and other State institutions cannot now be determined. Even though a way be found to maintain present incomes, there can be no doubt that further development, from State funds, will be seriously limited for many years to come. This is in no sense a statement of discouragement, as it is hoped that, as in the past, other sources of income may present themselves as needs arise.

The earthquake was destrucrive on a narrow belt extending along the coast from near Eureka in the north to Salinas in the south, a distance of about 300 miles. More than half the people of the state, and more than half the property are located in the affected district. The direct earthquake destruction was a minor matter, perhaps not exceeding $35,000,000, but the fire in San Francisco destroyed property valued at between $500,000,000 and $800,000,000, or roughly, one-fourth or one-fifth the assessable property of the State. One-third to one-fourth of this loss will probably be borne by insurance companies in other states and countries. Those State institutions which depend upon pro rata taxation for their support have lost a corresponding proportion of their income. The University of California loses $50,000 or $60,000 in this manner. It lost, besides, uninsured business property in San Francisco, whose annual rental was $60,000. The State of California will no doubt, repair these losses, as far as it is financially able; and there are no people in the world more ready

to support higher education in all its forms and phases, to the extent of their ability, than are the people who compose the commonwealth of California. They are both unusually practical and unusually interested in the ideal.

Four-fifths of the normal income of the Lick Observatory consists of State funds, assigned to it by the Regents of the University. These financial statements are made in deference to many inquiries from distant friends.

On the day following the earthquake, His Excellency, Governor Geo. C. Pardee, appointed a State Commission to investigate the scientific aspects of the phenomena. The commission consists of Professor A. C. Lawson, University of California, chairman; Professor J. C. Branner, Stanford University; Professor George Davidson, University of California; Professor Harry Fielding Reid, Johns Hopkins University; Dr. C. K. Gilbert, U. S. Geological Survey, Washington; Professor A. O. Leuschner, University of California, Secretary; and Director W. W. Campbell, Lick Observatory, University of California.

The Carnegie Institution of Washington has generously undertaken to defray the expenses of the investigation.

The work of the Commission is well organized and many facts of extreme interest have been established. The principal fact is that the earthquake was due to very extensive motion of the strata along a well-known geological fault that runs near the coast line. The motion was principally of the horizontal-shearing type, with few apparent evidences of any vertical component. The geological members of the commission have traced the *surface fissure* along the fault line practically continuously from the mouth of Alder Creek, just north of Point Arena, south to Fort Ross, where the fissure enters the ocean; thence from its reappearance in Tomales Bay, south to Bolinas Bay, where it again enters the ocean. It undoubtedly passes under the ocean about two miles out from the Golden Gate, as it re-enters the land some six or eight miles south of the Golden Gate, and follows the old fault line continuously south-south-east to a point a short distance southeast of Salinas. On the east side of the fissure the strata have moved south, and on the west side they have moved north, relatively. The relative motion appears to be a maximum in the Tomales-Bolinas region; about 20-25 miles northwest of San Francisco. A public road crossing the fault line at right angles has now an offset of seventeen feet at the fault line. A large tree standing exactly on the east edge of the fissure is now twenty-four feet south from the small roots which it left in the west bank of the fissure. A path crossing the fissure is offset eighteen feet; three trees formerly stood in a row about seven feet east of a small house. The fissure passes between them and the house and they are now eighteen feet southerly from the house. A barn is situated exactly over the fissure, some four-fifths of it being on the west side. Althongh badly wrecked, the superstructure remains with its foundation west of the fissure, but that part of the foundation lying east of the fissure has moved southward under the barn, through eighteen feet. A fence crossing the fault line is offset eighteen feet at the fissure. About twenty miles westward from Mount Hamilton, on the fault line, the offsets are about eight and one-half feet, as a maximum. All the offsets referred to are in the thick loamy soil, and it is possible that, on account of lag in the soft soil, the shear in the underlying rock stratum is larger.

Many interesting questions are raised as to disturbances in boundary lines between farms, in latitudes, azimuths, etc.

The same geological fault extends southeasterly throughout the State to the vicinity of the Colorado River, and perhaps further.

W. W. CAMPBELL.

PUBLICATION OF THE ASTRONOMICAL SOCIETY.
Number 108.

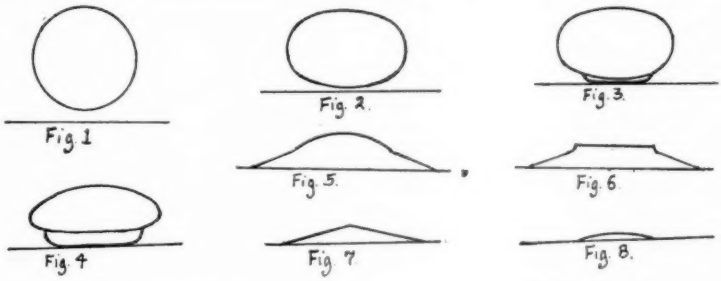
The Barrett-Serviss Star and Planet Finder. This is like the ordinary movable planisphere showing the stars which are visible to the naked eye at any hour of the night, on any day in the year, in the latitudes of the United States. It has as a new feature a scheme by which the places of the Sun, Moon and planets may be indicated approximately on any day during the years 1906 to 1925. The ecliptic is indicated by a red line on the chart and the degrees of longitude are marked on it. A pamphlet accompanies the chart containing tables of the longitudes of the planets and Moon at regular intervals for twenty years. A set of thumb tacks have the names of the planets, Sun and Moon printed upon them, and these, when stuck into the chart at the proper longitudes on the

Ecliptic line, show at a glance the position of each object in relation to the neighboring stars and to the horizon.

The chart is 15x15 inches square, is made of heavy cardboard securely nailed together and with fair usage should last a lifetime. It will be found a useful addition to the equipment of any school where elementary astronomy is taught. The price is five dollars.

On the Appearance of Sunset at Sea. On the 28th of August, 1904, not far from Long. 49° 46′ W, Lat. 45° 53′ N., there occurred a sunset of unusual splendor in a sky that was perfectly clear down to the horizon. The writer, a passenger on the Hamburg American Line steamer Belgravia witnessed the sight. The entire series of changes was most brilliant. When a little above the horizon the Sun's disk appeared circular as usual (fig. 1). When the Sun nearly reached the horizon it appeared as a beautiful flaming oval (fig. 2). When it touched the horizon there seemed to be a cushion under it, (fig. 3), which enlarged until the whole looked in shape like a dish with a cover (fig. 4). Then the lower portion expanded and looked like a cone (fig. 5.) Then the cover became flat (fig. 6.), then conical (fig. 7.), and at last spherical with slight curvature, (hg. 8.)

and finally disappeared. In an experience of about seventy-two days at sea, it was the only time the writer ever saw such a sunset. On the following morning the appearances at sunrise were somewhat similar and in reverse order, but were not nearly so marked. The notes and diagrams here submitted were made at the time and shown to other passengers who confirmed their accuracy. In the following figures the horizontal line represents the horizon.



E. D. Roe, Jr.

Syracuse University.
August, 1906.

Moulton's Introduction to Astronomy is a new book from the press of the Macmillan Company. It was published in April of this year, its author being Dr. Forest Ray Moulton, assistant professor of Astronomy in the University of Chicago, and author of an introduction to Celestial Mechanics.

The order of this new text for the study of the elements of astronomy is quite different from that followed by prominent, modern authors in this branch of study. After giving a preliminary outline this author deals in the usual way with reference points and lines. Then he considers the constellations, the naming of the stars, their magnitudes and their number. His way of presenting the constellations is useful and very attractive. The student is soon invited to a study of the sky in a way that must impress him thoroughly and lastingly if guided by a competent instructor. Such a plan awakens the student's interest in what he sees and knows from his survey of the sky, and not so much what he may have remembered from the pages of a book. His outline maps, the pages of easy test questions, his tables and illustrations show a balance of thought in his general plan for acquiring knowledge that is highly commendable.

The next step is to give instruction in regard to the nature and uses of the telescope, and a few other of the more important astronomical instruments. Careful attention is given to show the beginner in the study how the working parts of the telescope take up the rays from celestial objects, and manipulate them so as to place the human eye at great advantage in its search for many things which are beyond its unaided visual power. Nothing in regard to the make-up of a material instrument could be more interesting, than for a young person to see how like a sentient thing it works, when peering into the star depths, it reveals the wonderful treasures of knowledge therein stored up in waiting for the search of the human mind.

The problems respecting the Earth are presented in two chapters and cover nearly one hundred pages. The first is a study of the Earth at rest, and the second considers it as a body in motion. From the author's thorough acquaintance

with celestial mechanics, he is well prepared to give the latest and best that should be expected from a theme of universal interest like this. The different subjects of gravitation, time, and the tides are presented historically, graphically in simple calculation, and descriptively in a very satisfactory way.

The study of the Moon is complete in varied, general detail, including a broad historical sketch of the phenomena of its eclipses; and, next is considered the solar system. In this chapter considerable illustration is used which materially aids the student in relating the motions of so many heavenly bodies, at once, definitely and with a degree of clearness in thought and imagination that will be duly appreciated. We notice with interest that the new satellites of Jupiter and Saturn are given specific attention, and the minor planet Eros has full notice as it deserves.

The two illustrations on pages 30 and 362, taken from this publication, are some of the excellent work done by students and teachers at Goodsell Observatory of Carleton College. We regret that the author did not have the latest drawing of Jupiter's family of comets, printed in the April number of POPULAR ASTRONOMY, because it has some added features of interest which the earlier drawing did not contain. It is probable that this last drawing was prepared not early enough for his use in the new book.

The last two hundred pages are devoted to comets and meteors, the Sun, the evolution of the solar system, and the stars and the nebulæ. This order of themes is a variation from that more commonly followed in late standard text-books. There is certainly good reason for this order in the nature and the difficulty of the subjects, and probably it should be preferred, unless the order of distance of celestial objects from the Earth has more weighty reasons in its favor.

The work on these last themes is well sustained throughout, and, as a whole, the author has made a valuable contribution to the study of astronomy for al those who wish to read or study and know thoroughly the essentials of astronomy in its modern elementary method and style.

The Committee of Bibliography and of Astronomical Sciences, of the Royal Observatory of Belgium, has undertaken to publish a list of the Observatories and Astronomers of the whole world. A request for information, in the form of a list of questions, with a model reply relating to the Astronomical Service at the Uccle Observatory, Belgium, has been addressed to all the directors of observatories. In addition the list will include such astronomers (University professors, amateurs, etc.) who are not attached to any observatory, but are nevertheless actively engaged in astronomical research.

The information already sent will enable the Committee to draw up not only a list of observatories, with their geographical co-ordinates and the members of the staff, but also a table showing the astronomical activity of the whole world, thanks to the facts given as to the instruments at the disposal of each institution, the pieces of research undertaken, and the papers published.

We appeal to the directors of those observatories who have not yet received our question-form, or who have not yet forwarded a reply, as well as to unattached astronomers, and beg them to send us the information desired, or to repair any omissions, as soon as possible, addressed to the Chairman of the Committee, Prof. P. Stroobant, astronomer at the Royal Observatory of Belgium, Uccle, Belgium.

E. E. Barnard Honored. The May number of the *Bulletin de la Société Astronomique de France* announces that the Janssen prize again this year was awarded to the learned American astronomer, E. E. Barnard of the Yerkes

Observatory, for his noteworthy astronomical work, special mention being made of his discovery of the Fifth Satellite of Jupiter, his observations of the planet Mars, his measures of planetary disks, his admirable photographs of the Milky Way and his work on comets.

It will be recalled that once before Mr. Barnard has been the recipient of the Janssen gold medal given by the Academy of Science of France, and of the Arago and Laland prizes of the same society, and that he has also once been awarded the gold medal of the Royal Astronomical Society of England.

The Sun a Variable Star. In a paper prepared by Professor F. H. Bigelow of Washington, some very important conclusions are found, which, if true, will help to explain some hard problems in solar physics. We quote below:

"The sun is an immense solid-liquid mass, 866,000 miles in diameter, surrounded by a gaseous envelope which gradually changes to rarefied matter similar to that seen in vacuum tubes. Recent computations indicate that at the center of the sun there is a nucleus which instead of being gaseous is nearly as solid as the interior of the earth, with a temperature of about 10,000° centigrade; the average density of the whole sun is 1.43 times that of water, and this is located at half the distance from the center to the surface; the surface density is not far from 0.37 that of water, and its temperature, according to my calculation, ranges between 7000° and 6000° centigrade; at the surface there is a sudden transition from liquids to gases, which occurs as an explosion, caused by the uprush of liquids from the interior. The solar mass in such a physical state while rotating on its axis sets up a peculiar circulation, in consequence of which at the surface a huge wave is formed like a tide that advances most rapidly in the equatorial belt.

The body of the sun is divided up into layers of different temperatures, like a set of dice boxes inside one another, the longest axis extends through the sun from pole to pole, and these slide by one another at different velocities. This produces a stronger discharge of warm material in the polar regions than near the equator, so that on the sun the heat is greatest at the poles, reversing the conditions with which we are familiar in the earth's atmosphere.

The evidence for these facts is found in the study of the (1) sunspots, which occur in belts within 35° of the equator; (2) the faculæ or fleecy cloud-like forms found on all parts of the sun's surface, but most abundantly around the spots; (3) the prominences or gaseous flames projected in all latitudes above the disk; and (4) the coronas, which extend to great distances from the surface and somewhat resemble auroras in their nature."

Miss Mary E. Byrd's Resignation. After a most successful directorship of the Smith College Observatory, at Northampton, Massachusetts, lasting for nineteen years, Miss Byrd has voluntarily severed her connection, because of the acceptance by the Smith College authorities of money from Rockefeller and Carnegie.

Miss Byrd's devotion to principle and those principles the high old Puritan ones, is what might be expected from her ancestry and early environment, for her father's was the church known as "the abolition" one in Kansas' anti-slavery days and many were the persecutions suffered.

With this background in her life it is easy to see that for conscience sake she would yield the position she has long held with honor, and upon which she was dependent for support, and whether accepting her logic or not, no one not hardened by the commercialism of today can fail to respect her fidelity to her principles and to admire her courage.

Miss Byrd was graduated in 1878 from the University of Michigan; after three years of high school teaching she spent one year at Harvard College

Observatory studying under Dr. E. C. Pickering: the next four years Miss Byrd was employed as assistant in the observatory at Carleton College, and instructor in mathematics and astronomy. During this time Goodsell Observatory was built and at the laying of its corner stone she delivered an able address on "Popular Fallacies about Observatories." From Goodsell Observatory Miss Byrd went directly to Smith College Observatory.

POPULAR ASTRONOMY readers will be interested to know that mounting, testing and adjusting the instruments in the Smith College Observatory developed her method of teaching astronomy as a laboratory science, which has been given to the public in her book "Laboratory Manual in Astronomy." Miss Byrd conducted a "longitude campaign" with the Harvard College Observatory, and has made valuable comet observations, ascertaining positions by micrometer measures of their distances from known stars. In additon to her Manual Miss Byrd has written for the ASTRONOMICAL JOURNAL, ASTRONOMISCHE NACHRICHTEN, SIDEREAL MESSENGER and our own POPULAR ASTRONOMY, the latest contributions being her sketch of the life of Miss Anna Winlock, and the helpful series of four articles on "Astronomy in the High School."

PUBLISHER'S NOTICES.

Contributors are asked to prepare copy carefully, and write *all proper names very plainly*. If other language than the English is used to any considerable extent it should be type-written. Manuscript to be returned should be accompanied by postage for that purpose.

All Drawings for publication should be done in India ink, twice the size that the cut will be on the printed page. The lines, figures and letters should be made even, very smooth and uniformly black in every part of the copy, in order to secure the best reproductions possible by the modern quick processes of engraving now most generally used.

Proofs will generally be sent to authors living in the United States, if copy is furnished before the first of the month preceding that of publication. We greatly prefer that authors should read their own proofs, and we will faithfully see that all corrections are made in the final proofs.

Renewals.—Notices of expiration of subscription are sent directly after the last number of this publication for which payment has been made. It is especially requested that subscribers will send renewal, or order for renewal, promptly as this publication will not be continued beyond the time for which it has been ordered.

Astronomical News.—It is very much desired on the part of the management, that brief news paragraphs of astronomical work in all the leading observatories of the United States be furnished to this publication, as regularly and as often as possible.

The work of amateur astronomers, and the mention of "personals" concerning prominent astronomers will be welcome at any time.

The building and equipping of new observatories, the manufacture, sale or purchase of new astronomical instruments, with special reference to improvements and new designs, and the results of new methods of work in popular language, will be deemed very important matter and will receive prompt attention. It is greatly desired that all persons interested bear us in mind and promptly respond to these requests.

Messrs. Wm. Wesley & Son, 28 Essex Street, Strand, London, England, are our sole European agents.

Reprints of articles for authors, when desired, will be furnished in titled paper covers at small cost. Persons wanting reprints should order them when the manuscript is sent to the publisher. They cannot be furnished later without incurring much greater expense.

Subscription Price Changed. Beginning with the January number the price of Popular Astronomy a volume, of ten numbers each, to subscribers living in the United States, its territory, Canada and Mexico was changed to $3.50; the price to all others is $4.00; in each case payable strictly in advance.

Back volumes or single numbers are still on sale at the old prices, $2.50 and 30 cents, respectively.

WM. W. PAYNE,
Northfield, Minn., U. S. A.